JOURNAL OF
THE INSTITUTION OF
CIVIL ENGINEERS.

No. 3. 1941–42.
JANUARY 1942.

JOINT MEETING WITH THE INSTITUTION OF MECHANICAL ENGINEERS.

16 December, 1941.

Professor CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S. President Inst. C.E. in the Chair, supported by

Mr. WILLIAM ARTHUR STANIER, President Inst. Mech. E.

The following two Papers were read and discussed [1], and on the motion of the Chairman the thanks of the Meeting were accorded to the Authors.

Paper No. 5243.

(1) "Hammer-Blow in Locomotives: can it not be abolished altogether?" †

By Sir Harold Nugent Colam, B.A., M. Inst. C.E., and Major John Douglas Watson, R.E., B.Sc. (Eng.), Assoc. M. Inst. C.E.

TABLE OF CONTENTS.

Introduction.

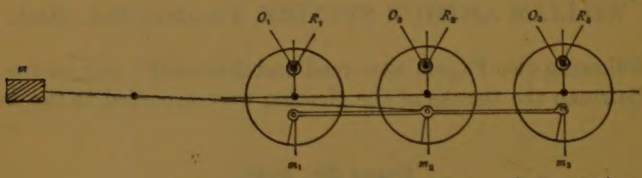
At the outset it is advisable to reiterate exactly what "hammer-blow" is, in order to define the terms used in this Paper, which deals with outside-cylinder locomotives only.

† Correspondence on this Paper can be accepted until the 15th April, 1942, and will be published in the Institution Journal for October 1942.—Sec. Inst. C.E.

[1] A report of the Discussion will be published in a subsequent number of the Journal (probably February).

Fig. 1 is a diagrammatic representation of one side of a six-coupled locomotive. Attached to the wheels are crank-pins, connecting-rods, and coupling-rods which rotate at anything up to seven revolutions per second, and develop considerable centrifugal forces, which at one point tend to lift the wheels off the rails, and at another point exert severe downward pressures on the rails. The first object in balancing a locomotive is to eliminate these effects, and this is done by introducing counterweights in the wheels diametrically opposite to the crank-pins. For the purpose of this Paper, the counterweights are represented by their equivalent masses at crank-pin radius, and the masses required for this first step in balancing, called "balancing the rotating masses", are shown in the diagram as black areas marked R_1, R_2, R_3. The rotating masses ought to be completely balanced. It is generally believed that they are. In practice, very often they are not, as will be shown later.

Fig. 1.



In *Fig. 1*, *m* represents the mass of the piston, piston-rod, cross-head, and part of the connecting-rod. This mass oscillates rapidly forwards and backwards, and its acceleration and deceleration produce oscillating reactions tending to make the locomotive proceed in jerks. As there is another similar mass on the other side of the locomotive, oscillating out of phase with the one on the near side, an oscillating couple is set up about a vertical axis, tending to make the locomotive "nose", or strike first one rail and then the other. This is objectionable, and in extreme cases might be dangerous. The ideal way to counter it would be to provide equal oscillating masses in opposite phase, but this is difficult, although not impossible. The method adopted is to increase the masses R_1, R_2, and R_3 by certain amounts, shown diagrammatically as white areas surrounding them, and labelled O_1, O_2, and O_3. These are called "overbalances" as they are over and above the masses R_1, R_2, and R_3 required to balance the rotating masses. If *m* is 1,000 lb., and O_1, O_2, and O_3 together are 400 lb. there is said to be an overbalance of 400 lb., or a 40-per-cent. overbalance. These masses O_1, O_2, and O_3 set up centrifugal forces, the horizontal components of which are equivalent to masses oscillating in opposite phase to *m*.

Unfortunately, these centrifugal forces have vertical components also which reintroduce the troubles removed by balancing the rotating masses

tending to lift the wheel off the rail at one time and to increase the pressure on the rail at another time. It is this increase of pressure which is called "hammer-blow." It increases the stresses in rails and bridges and is in every way objectionable.

The object of this Paper is to submit evidence in support of the contention that in modern locomotives overbalance is unnecessary.

Preliminary Investigations into the Balancing of Existing Locomotives.

Evidence has been accumulated from investigations which started in 1926 after the Indian Bridge Committee had been studying American experiments on stresses in railway track. The reports[1] on these experiments contained a large amount of information about the balancing of American locomotives and the evil effects on the track of hammer-blow. The first step was to determine the values of R and O in existing locomotives. Some surprising results were obtained. With metre-gauge locomotives, it was found that the overbalance ranged from plus 51 per cent. to minus 15 per cent. In other words, in many locomotives, not only was O non-existent, but also R_1, R_2, and R_3 together were not sufficient to balance the rotating masses. The worst figure, minus 15 per cent., was found in fast-running 4–6–0 passenger locomotives of the Madras and Southern Mahratta Railway, which had given eminently satisfactory service for many years. No-one, drivers, foremen, or those responsible for upkeep, had any complaints to make against them. These discoveries gave rise to the contention that overbalance was either entirely unnecessary, or at least could be much smaller than was generally considered necessary. Standard locomotives were then being designed, and have since been put into service, with overbalance of 66 per cent.

Almost more startling was the discovery that in every one of the large number of locomotives examined, the counterweight on the main driving-wheels, $R_2 + O_2$, was inadequate to balance the rotating masses on that wheel. The result was a heavy hammer-blow under the crank-pin; usually hammer-blow is on the opposite side of the wheel.

Actually, the minus-15-per-cent. case was not the fault of the designers or manufacturers. At some date after delivery, the method of attaching the tires had been altered, and in the process the outermost and most effective part of the counterweight had been machined off, without consideration of the consequences. As a matter of interest, the only complaint against these locomotives was that they tended to wear their main driving-wheel tires unduly on the crank-pin side. The investigation indicated the cause of this, namely that, owing to the failure to balance

[1] Reports of the Special Committee on Stresses in Railroad Track. Transactions Amer. Soc. Civ. Engrs., Jan. 1918, Feb. 1920, *et seq.*; Technical Paper No. 245 Indian Railway Board, 1925.

the rotating masses, there was a heavy pressure between tire and rail under the crank-pin, reinforced by the vertical component of the steam thrust in the connecting-rod.

Similar investigation in broad-gauge locomotives revealed overbalances ranging from 80 per cent. to 13 per cent., but, at that time, no negative overbalances. Failure to balance the rotating masses on the main driving-wheels was, however, found in many cases. Incidentally, the failure to balance rotating masses on main driving-wheels was almost universal in American locomotives, with extremely evil results. The reason was that with the enormous increase in locomotive weights, the values of m had increased greatly; but the wheels had remained at about the same diameter and incapable of accommodating the counterweights required.

A parallel investigation [1] on the South Indian Railway showed similar results. In one 4–6–0-type passenger locomotive, in no wheel were the rotating masses balanced, and there was a total underbalance of not less than 50 per cent. In other words, far from the reciprocating masses being partly balanced, their weight of 403 lb. was virtually increased to 600 lb.; but there were no evil results. Admittedly speeds did not normally exceed 40 miles per hour. Again, in not one of the three types examined were the rotating masses on the main driving-wheel balanced. These results were published in 1928.

In 1928, one of the Authors, in discussing his results with a member of the British Bridge Stress Committee, contended that overbalance was unnecessary in most cases, if not in all. He learned then that the British Bridge Stress Committee had discovered a similar, but worse, state of affairs in British locomotives. The "overbalance" ranged from plus 86 per cent. to minus 19 per cent., and in many cases the hammer-blow of a single wheel exceeded the hammer-blow of the whole locomotive. These results were entirely unsuspected and revealed an almost unbelievable state of chaos, but the inference was that if there was any virtue in overbalance, the British companies would surely have agreed upon approximately the same value on all railways.

In 1930, one of the Authors published a Paper [2] giving some of the facts discovered up to that time. The argument was, that if U denoted the unbalanced proportion of the reciprocating parts R, M denoted the mass of the engine without tender, and L denoted its length, the effect of the unbalanced proportion of R in causing oscillating variations in draw-bar pull was proportional to $\frac{UR}{M}$, and the effect tending to produce "nosing" was roughly proportional to $\frac{UR}{ML^2}$ in locomotives of similar type and gauge.

[1] Quarterly Technical Bulletin, Indian Railway Board, vol. i, No. 8 (Jan. 1928).

[2] Sir Harold N. Colam, "Should the Present Policy of Balancing Two-thirds of the Reciprocating Masses of the Locomotive be Reconsidered?" Quarterly Technical Bulletin, Indian Railway Board, vol. ii (1929–32), No. 17, p. 11 (April 1930).

In both cases the effect was proportional to $\frac{UR}{M}$. It was shown that as the weight of locomotives increased, the ratio $\frac{R}{M}$ decreased rapidly and steadily. This being so, U could be increased without the effects being any worse than they had been in the past. Yet the fact was that, owing largely to the state of affairs revealed by the British Bridge Stress Committee, designers were paying more attention to balancing and U was decreasing instead of increasing. Moreover, they ignored American practice which, for many years, had been to leave unbalanced reciprocating masses equal to 0·25 per cent. of the mass of the locomotive; which in practice gave effect to the argument advanced above.

Experiments on the Reduction of Overbalance.

By 1930, a large number of new standard locomotives were in use in India with 66⅔ per cent. of the reciprocating masses balanced. Permission was obtained to fit temporary weights on the crank-pin side of the wheel, sufficient to cut down the overbalance to 33 per cent., on three of the major railways in India. The object of the experiment was not divulged, but drivers and maintainers were asked to report in due course whether any difference was noticed in the running or maintenance of the locomotives. The reports, which came in for some years, were entirely negative—except that one driver maintained that his locomotive "started, ran, and stopped better." As a result of the experiment, the decision was taken to cut down the overbalance to 33⅓ per cent. in these and future locomotives of the same type. This was a step in the right direction, but there was plenty of evidence to suggest that the overbalance might be cut out altogether.

Meanwhile, on the Madras and Southern Mahratta Railway experimental work had been proceeding cautiously. In May 1932, two "YC"-class (heavy metre-gauge passenger) locomotives were rebalanced taking into account 20 per cent. of the reciprocating parts. Trials were also made with "W"-class broad-gauge locomotives with no reciprocating parts balanced. In June 1935, the chief mechanical engineer of the railway reported that "W"-class engine No. 776, which had been rebalanced for 20 per cent. reciprocating parts, had run 40,000 miles, and that wear on axleboxes and side-rod bushes was perfectly normal. "W"-class engine No. 773, which had been rebalanced with no reciprocating parts balanced, had been running for 4 months and was reported to ride perfectly satisfactorily. This type of locomotive came to be known as the "RO" type; and in this Paper "RO" indicates an engine with no reciprocating parts balanced.

By that time sufficient data was at hand to enable the chief mechanical engineer to conclude that there was no apparent reason why the propor-

tion of reciprocating parts balanced should not be reduced to a maximum of 20 per cent. There were also indications that it might be possible to cut out all the reciprocating balance, and he was prepared to continue the experiments on these lines, particularly in the case of the metre-gauge engines, in which the existing state of balance was in many cases very unsatisfactory.

Comparative Trials of Locomotives with Balanced and Unbalanced Reciprocating Parts.

In September 1935, the junior Author took part in a trial of an "XB"-class locomotive. The first run was made with the engine unmodified, and the second run, on the same day, with the engine fitted with temporary counterbalance weights calculated to reduce the amount of the reciprocating parts balanced to zero. Hallade track-records were made during both runs. Speeds of 76 and 79 miles per hour were attained on the two runs. Unfortunately the engine selected for these tests had run 50,000 miles since the last heavy repair, and the side-rods, big-ends, and little-ends were knocking badly. In the first trial, a pronounced side-sway of the tender was observed. In the second trial, the fore-and-aft forces made themselves felt alarmingly, but there was no oscillation; the side-sway of the tender was less noticeable. The chief mechanical engineer and the junior Author rode on the foot-plate in front of the smoke-box, and the Hallade recorder was placed between them, just behind and above the buffer-beam on the centre-line of the locomotive. Portions of the Hallade records are reproduced in Figs. 2, Plate 1. At the conclusion of the trials the locomotive was taken into shops for examination; it was found that the wedges required adjustment, whilst the big-end and small-end brasses and also the side-rod bushes, needed attention.

To some extent this trial was a set-back to the contention that it was unnecessary to balance reciprocating parts; but the junior Author considered that too many extraneous factors had affected the issue for any definite conclusion to be drawn. The knock was very pronounced during the second run at 79 miles per hour with no reciprocating parts balanced. The running was, however, steady and the transverse oscillations measured from the Hallade record bore no relation to the period of the oscillating forces, which was approximately $\frac{1}{6}$ second. Fortunately at a later stage it was found possible to repeat this trial with a larger number of "XB"-class locomotives, including five of the "XB/RO" class. Tests were also made with "YC"-class metre-gauge locomotives.

In 1938, the Bhita disaster on the East India Railway focused attention on the "XB" type of engine, and the Madras and Southern Mahratta Railway, which owned many engines of this type, deputed a locomotive officer to make special trials on all "XB" engines available. Of the twenty-one engines tested, five were "RO" engines. Later, the Authors

examined the records to see if data were available for comparing ordinary and "RO" engines. The difficulty was that the "RO" engines had all been overhauled recently, whilst many of the others had done large milages since the last overhaul. Five, however, were selected, which had run as nearly as possible the same milages as the "RO" engines, and for comparison "RO" and "non-RO" engines were grouped in pairs of approximately equal milages. The Hallade records for two of these pairs of locomotives over a distance of 1 mile are reproduced in Figs. 3, Plate 1.

The Authors have come to the conclusion that there was little to choose between the two engines of each pair, and what little there was cannot be attributed to their state of balance. It should be noted that in none of the runs selected was the running so rough as to result in any comment from the officer on special duty who accompanied the trials. In the course of twenty-one runs, three cases of severe oscillation did occur, but in no case was an "RO" engine involved. It may be added, however, that those three engines had done between 80,000 and 110,000 miles, whilst no "RO" engine had done more than 69,000 miles since the last heavy repair.

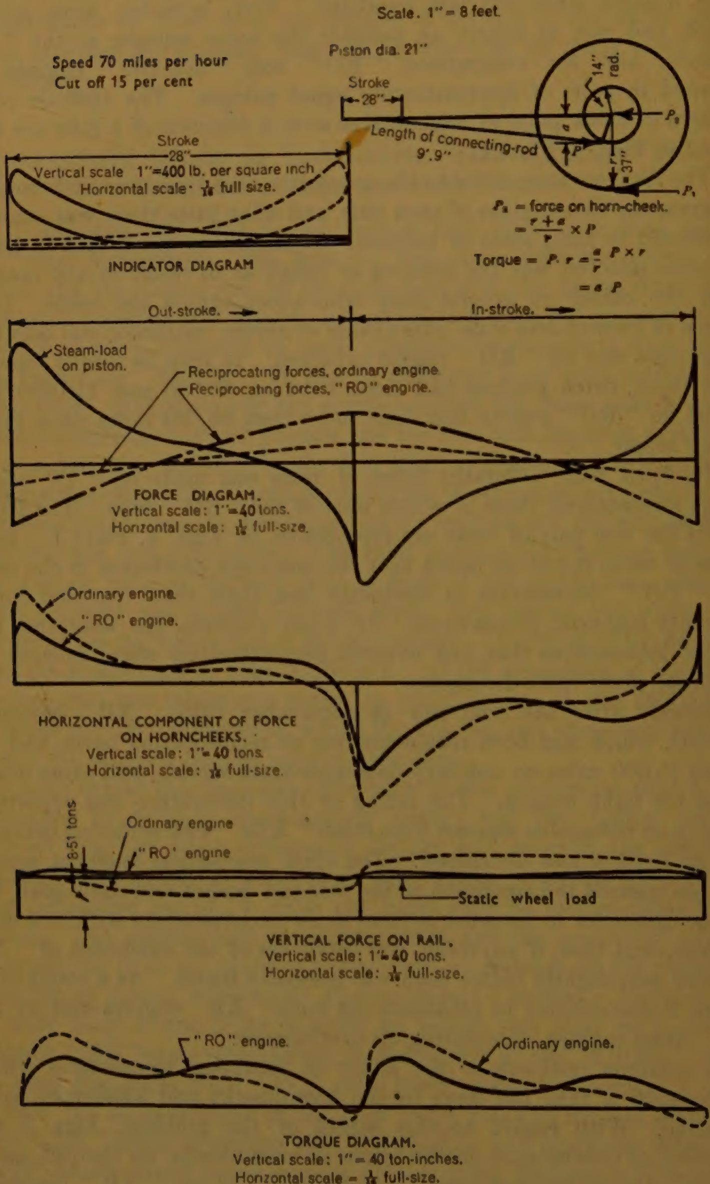
In April 1939, a further series of tests was made on "YC" metre-gauge locomotives, three of which were of the "RO" type. The Hallade charts for one pair of tests are reproduced in Figs. 4, Plate 1. In this series of tests, it will be noted that the sideways oscillation in the case of the "RO" locomotives is distinctly less than that recorded for the normally-balanced locomotives. In other respects, the diagrams for a pair of locomotives that had covered approximately equal milages since overhaul, show little divergence.

Shortly after the trial run in September 1935, "XB" locomotive No. 202, which had been rebalanced for no reciprocating parts, had completed 55,000 miles on ordinary passenger-train service, and came into the shops for light repairs. The riding of this locomotive was reported to differ in no noticeable manner from other "XBs" with orthodox balancing, and no defects had developed. The chief mechanical engineer reported that, as regards the condition of the side-rod bushes and draw-gear, there was no difference in the wear beyond those variations met with in ordinary practice, and that, if anything, the condition of the axleboxes of "XB" No. 202 was slightly better than was normally found. As a result of this report, it was decided to rebalance six more "XB" engines and six more "W"-class engines, eliminating all overbalance.

A common criticism of the policy of balancing locomotives without overbalance is that the wear in the horn-cheeks and axleboxes will be excessive. With regard to this aspect of the problem, *Figs. 5* show the effect of overbalance on the forces at horn-cheeks, on the rail, and on torque. An indicator-diagram is reproduced of an "XB" locomotive taken at a speed of 70 miles per hour with 15-per-cent. cut-off. From this

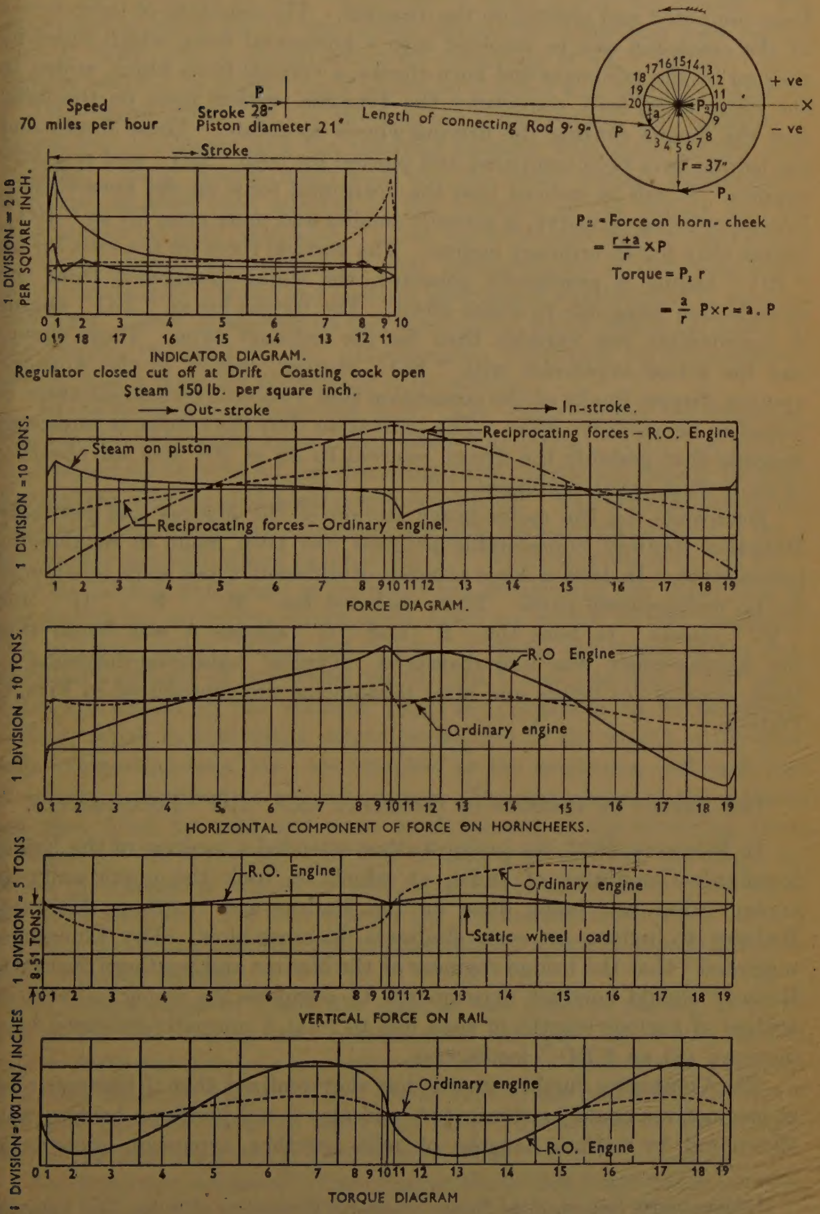
Figs. 5.

(*a*)


Scale. 1" = 8 feet.
Piston dia. 21"
Speed 70 miles per hour
Cut off 15 per cent
Stroke
28"
14" rad.
37"
Length of connecting-rod 9'.9"
Stroke
28"
Vertical scale 1"=400 lb. per square inch
Horizontal scale · 1/24 full size.
INDICATOR DIAGRAM
P₁ = force on horn-cheek.
Torque
Out-stroke.
In-stroke.
Steam-load on piston.
Reciprocating forces, ordinary engine
Reciprocating forces, "RO" engine.
FORCE DIAGRAM.
Vertical scale: 1"=40 tons.
Horizontal scale: 1/24 full-size.
Ordinary engine.
"RO" engine.
HORIZONTAL COMPONENT OF FORCE ON HORNCHEEKS.
Vertical scale: 1"=40 tons.
Horizontal scale: 1/24 full-size.
8·51 tons
Ordinary engine
"RO" engine
Static wheel load
VERTICAL FORCE ON RAIL.
Vertical scale: 1"=40 tons.
Horizontal scale: 1/24 full-size.
"RO" engine.
Ordinary engine.
TORQUE DIAGRAM.
Vertical scale: 1" = 40 ton-inches.
Horizontal scale = 1/24 full-size.

Figs. 5.

(*b*)


Speed
70 miles per hour
Stroke 28"
Piston diameter 21"
Length of connecting Rod 9' 9"
+ ve
− ve
r = 37"
P₂ = Force on horn-cheek
= (r+a)/r × P
Torque = P₁ r
= a/r P × r = a. P
Stroke
1 DIVISION = 2 LB PER SQUARE INCH.
INDICATOR DIAGRAM.
Regulator closed cut off at Drift Coasting cock open
Steam 150 lb. per square inch.
Out-stroke
In-stroke.
1 DIVISION = 10 TONS.
Steam on piston
Reciprocating forces – R.O. Engine
Reciprocating forces – Ordinary engine.
FORCE DIAGRAM.
R.O Engine
Ordinary engine
HORIZONTAL COMPONENT OF FORCE ON HORNCHEEKS.
1 DIVISION = 5 TONS
8·51 TONS
R.O. Engine
Ordinary engine
Static wheel load
VERTICAL FORCE ON RAIL
1 DIVISION = 100 TON / INCHES
Ordinary engine
R.O. Engine
TORQUE DIAGRAM

the steam-pressure on the piston has been deduced for the out- and in strokes, and this has been reproduced as a curve in the force-diagram. The reciprocating forces for an ordinary engine and an "RO" engine have been computed and plotted on the diagram. The resultant of these forces at the crank-pin can be resolved into a horizontal force which must be resisted by the axleboxes and horn-cheeks, a vertical force which, added to the static wheel-load, constitutes the dynamic vertical force on the rails, and the torque causing the driving-wheels to rotate. These forces and the torque have been computed and plotted for both "RO" and ordinary engines. It will be noticed that the horizontal force on the horn-cheeks, instead of being excessive, is actually smaller and more even for an "RO" engine than for an ordinary engine. The vertical force on the rails for an "RO" engine is practically constant, the slight divergence from the straight line being due to steam effect. The torque for an "RO" engine is considerably less variable than for the ordinary type. These curves and the actual experience with "RO" engines, should, in the Authors' opinion, dispose finally of the contention that without overbalance there is bound to be excessive wear. The indication that the torque is improved suggests that possibly the driver referred to on p. 201 was an observer of more than usual acuteness.

Meanwhile, on the metre-gauge section of the Madras and Southern Mahratta Railway, considerable progress had been made in rebalancing locomotives. In 1936 a large number of different types were rebalanced for no reciprocating parts. These included the "M", "P", "G", and "YC" classes. In both the "P" and "G" classes it was found that the driving-wheel was underbalanced. Typical balancing-diagrams of these locomotives before and after rebalancing are reproduced in Figs. 6, Plate 2.

The Effect on Bridges of Ordinary and "RO" Locomotives.

In February, 1937, the junior Author attended a meeting of the Bridge Standards Committee of India, at which he took the opportunity to explain what was being done on the Madras and Southern Mahratta Railway to reduce or even eliminate hammer-blow. The Committee suggested [1] that the bridge engineer of the Madras and Southern Mahratta Railway should conduct experiments to compare the impact effects on bridges of various lengths of span due to: (1) a normally-balanced locomotive; (2) an "RO" locomotive.

The Committee further stated that they realized that if hammer-blow in locomotives could be eliminated, and also if rail-joints on bridges were eliminated by welding lengths of rails together, expansion-joints being

---

[1] Seventeenth Report of the Bridge Standards Committee of India, 23rd February to 2nd March, 1937. Indian Railway Board.

provided over piers where necessary, two of the main causes of impact on bridges would disappear and there would be a good case for revision of the impact formula to take cognizance of these special conditions. The experiments asked for by the Bridge Standards Committee were carried out in 1938, with a special test-train consisting of an "XB/RO" locomotive coupled by empty bogie passenger-coaches to a normally-balanced "XB" locomotive. As the two engines were coupled, the variation of speed was eliminated and the resulting impacts were more readily comparable. Early records made with the De Forest scratch extensometer appeared to have been affected by the vibration of the girders, and the results were far from consistent. Later, the difficulties were to some extent overcome, but it was considered that measurements of deflexion would give more reliable results, and a simple instrument was designed to measure deflexion. Most of the results and conclusions which follow are based on the records obtained by the deflectometer, supported by extensometer results where these are considered to be reliable.

In the series of tests described, only "XB"-class engines, the characteristics of which are widely known, were used. The normal "XB/1" locomotive is balanced for 66 per cent. reciprocating parts distributed equally between the leading, driving, and trailing coupled wheels. The principal balancing data and calculations for hammer-blow of a normally-balanced "XB/1" locomotive are reproduced in Appendix I. When converting an "XB/1" into an "XB/1/RO", and in general when rebalancing any other type of locomotive for no reciprocating parts, holes are drilled in the crescent of the balance-weights, taking out weights of metal equivalent to the out-of-balance masses as calculated above. In actual practice, a few more holes are drilled in the crescent than are calculated to be necessary. Collars, which in equivalent weight correspond to the weight of the side-rods, connecting-rods, etc., are attached to the crank-pin, and each pair of wheels is mounted on roller-bearings. The extra holes in the crescent are then filled by trial and error until balance of the revolving parts is attained. It is realized that this method is of doubtful accuracy, as, unless the wheels are rotated at speed, it cannot be ascertained which wheel is out of balance. For this reason, the mechanical department have a dynamic balancing machine under construction which is expected to give more accurate results.

As wide a range of spans was used as was possible, namely, from 12 feet to 131 feet, taking into consideration the fact that it was feasible only to carry out tests on the north-west line of the Madras and Southern Mahratta Railway, where "XBs" are in regular use and sufficient time is available between trains to carry out tests. Particulars of the bridges used in the tests are given in Table I on p. 208.

The test-train consisted of one empty third-class bogie-coach coupled between engine No. 212, "XB/1/RO", and engine No. 213, "XB/1", except for the 131-foot span bridge. On this bridge, two third-class bogies

TABLE I.—PARTICULARS OF BRIDGES.

Clear span	12′ . 0″	15′ . 9″	20′ . 3″	30′ . 0″	50′ . 0″	64′ . 0″	131′ . 0″
Bridge number	385	348	184	347A	183	393	688
Milage	134/22–23	128/1–2	79/23–24	127/23–24	79/21–22	135/11–136/3	211/21–212/7
Section			North West Line (Broad Gauge),				
Description of girder *	S.C.	S.C.	S.C.	S.P.	S.P.	S.P.	S.T.
Effective span	13′ . 7½″	17′ . 7½″	22′ . 3½″	31′ . 9″	52′ . 6″	67′ . 5″	136′ . 0″
Overall length	15′ . 0″	19′ . 6″	24′ . 4″	33′ . 6″	55′ . 0″	69′ . 10″	138′ . 4″
Ratio of effective length to depth	9·75	10·3	12·9	9·76	11·88	11·35	5·91
Abutment or intermediate span	Abutment	Abutment and Pier No. 1	Abutment	Intermediate No. 4 Span	Abutment	Abutment and Pier No. 1	Intermediate No. 12 Span
Gradient	Level	Level	1 in 660	Level	1 in 660	Level	Level
Span on straight or curve	Straight	Straight	Straight	Straight	Straight	Straight	Straight
Square or skew	Square	Square	Square	Square	Square	Square	Square
Distance of rail-joint from centre of span	None on span	None on span	Rail-joint dead at centre of span	—	—	—	—
To north	—	—	—	12′ . 10½″	23′ . 10½″	7′ . 3″	14′ . 3″ 54′ . 3″
To south	—	—	—	—	12′ . 1½″	22′ . 9″	25′ . 9″ 65′ . 9″
Weight of each main girder: tons	1·02	1·52	2·38	3·78	10·78	16·05	56·0
Total dead-load on span: tons	3·13	4·56	6·69	10·14	26·56	39·0	167·92
Frequency of vibration, as given by formula $n_0 = \frac{1}{\sqrt{\frac{w+p}{p} \cdot d}}$	—	—	—	—	—	6·2	3·77
Critical speed: miles per hour	—	—	—	—	—	80	49

* S.P. denotes steel plate; S.C. denotes steel compound of R.S.J. and plates; S.T. denotes steel truss girder.

TABLE II.—DEFLECTOMETER RESULTS.

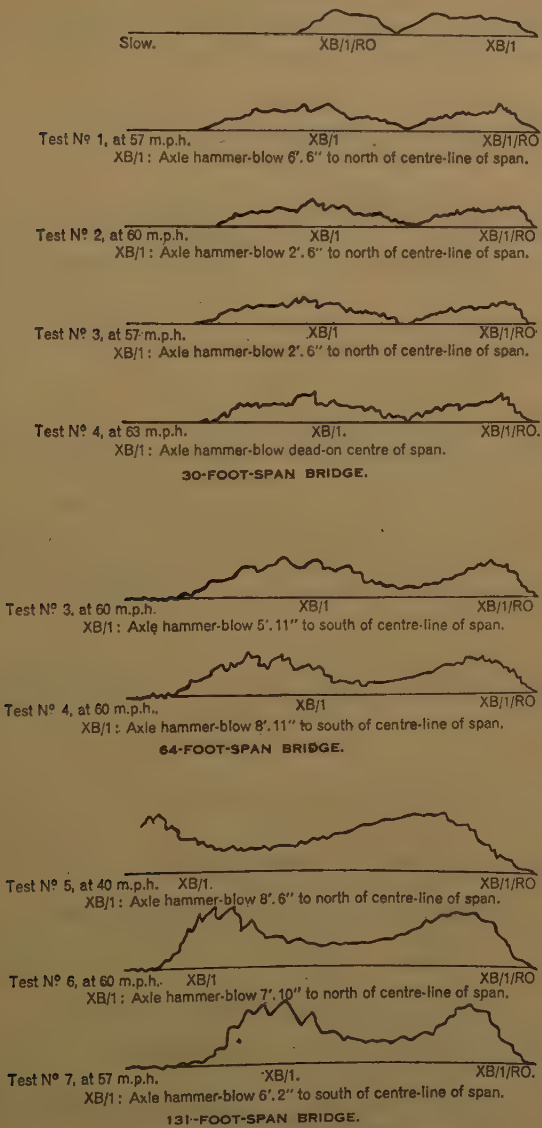
Test number.	Speed: miles per hour.	Engine No. 212, XB/1/RO. Distance from centre-line of span to point x on tire of left-hand driving wheel: feet. inches.	Maximum deflexion of right-hand girder: inches.	Corresponding impact: per cent.	Maximum deflexion of left-hand girder: inches.	Corresponding impact: per cent.	Engine No. 213, XB/1. Distance from centre-line of span to point x on tire of right-hand driving-wheel: feet. inches.	Maximum deflexion of right-hand girder: inches.	Corresponding impact: per cent.	Maximum deflexion of left-hand girder: inches.	Corresponding impact: per cent.	Calculated deflexion: inches.	Calculated impact: per cent.
					12-Foot Span: Bridge No. 385.								
	Slow	—	0·05	—	0·05	—	—	0·05	—	0·05	—	0·053	—
1	55	7. 8 N.	0·055	10·0	0·055	10·0	4. 1 N.	0·06	20·0	0·06	20·0		
2	57	2. 3 N.	0·055	10·0	0·06	20·0	0. 6 S.	0·06	20·0	0·06	20·0	0·11	100
3	60	5. 9 S.	0·055	10·0	0·06	20·0	8. 2 S.	0·06	20·0	0·06	20·0		
4	60	7. 5 N.	—	—	0·06	20·0	1. 11 N.	—	—	0·06	20·0		
					15-Foot Span: Bridge No. 348.								
	Slow	—	0·10	—	0·09	—	—	0·10	—	0·09	—	0·09	—
1	60	5. 0 N.	0·11	10·0	0·10	11·1	1. 6 S.	0·13	30·0	0·10	11·1		
2	60	0. 6 N.	0·12	20·0	0·095	5·5	3. 11 S.	0·11	10·0	0·10	11·1	0·18	100
3	65	4. 3 N.	0·11	10·0	0·095	5·5	5. 3 S.	0·12	20·0	0·11	22·2		
					20-Foot Span: Bridge No. 184.								
	Slow	—	0·11	—	0·11	—		0·11	—	0·11	—	0·16	—
1	60	1. 0 N.	0·14	27·3	0·16	45·5	8. 3 S.	0·15	36·4	0·19	72·7	0·31	96·6
2	60	2. 10 S.	0·14	27·3	0·15	36·4	7. 8 N.	0·16	45·5	0·15	36·4		
					30-Foot Span: Bridge No. 347A.								
	Slow	—	0·15	—	0·16	—	—	0·15	—	0·16	—	0·18	—
1	57	6. 0 S.	0·16	6·7	0·17	6·2	6. 6 N.	0·17	13·3	0·19	18·8		
2	60	7. 0 N.	0·17	13·3	0·17	6·2	2. 6 N.	0·19	26·7	0·20	25·0	0·33	84·7
3	57	0. 6 N.	0·17	13·3	0·18	12·5	2. 6 N.	0·19	26·7	0·20	25·0		
4	63	6. 1 S.	0·18	20·0	0·20	25·0	Dead centre	0·21	40·0	0·21	31·3		
					50-Foot Span: Bridge No. 183.								
	Slow	—	0·22	—	0·21	—	—	0·22	—	0·21	—	0·38	—
1	55	—	0·25	13·6	—	—	—	0·27	22·7	—	—		
2	60	—	0·27	22·7	—	—	—	0·29	31·8	—	—		
3	60	6. 8 N.	0·27	22·7	0·25	19·1	2. 11 S.	0·27	22·7	0·27	28·6	0·63	66·7
4	57	0. 1 N.	0·26	18·2	0·26	23·8	5. 7 S.	0·26	18·2	0·29	38·1		
5	60	7. 3 S.	0·26	18·2	0·25	19·1	8. 8 S.	0·28	27·3	0·26	23·8		
					64-Foot Span: Bridge No. 393.								
	Slow	—	0·25	—	0·25	—	—	0·25	—	0·25	—	0·39	—
1	57	8. 3 S.	0·27	8·0	0·27	8·0	3. 5 N.	0·30	20·0	0·31	24·0		
2	60	1. 4 N.	0·27	8·0	0·26	4·0	1. 6 S.	0·29	16·0	0·30	20·0	0·61	57·8
3	60	8. 11 S.	0·26	4·0	0·27	8·0	5. 11 S.	0·28	12·0	0·29	16·0		
4	60	2. 4 N.	0·26	4·0	0·27	8·0	8. 11 S.	0·28	12·0	0·29	16·0		
					Engine No. 214.—XB/1/RO. 131-*Foot Span: Bridge No.* 688.								
	Slow	—	0·43	—	0·43	—	—	0·43	—	0·43	—	0·60	—
1	40	—	0·45	4·6	0·45	4·6	2. 3 N.	0·47	9·3	0·47	9·3	—	—
2	30	—	0·45	4·6	0·43	Nil	—	—	—	—	—	—	—
3	30	—	0·45	4·6	0·44	2·3	4. 1 N.	0·45	4·6	0·44	2·3	—	—
4	40	—	0·44	2·3	0·43	Nil	6. 2 N.	0·46	7·0	0·46	7·0	—	—
5	40	—	0·43	Nil	0·43	Nil	8. 6 N.	0·47	9·3	0·48	11·6	—	—
6	60	—	0·44	2·3	0·43	Nil	7. 10 N.	0·48	11·6	0·48	11·6	0·82	35·9
7	57	—	0·44	2·3	0·43	Nil	6. 2 S.	0·48	11·6	0·48	11·6		

TABLE III.—EXTENSOMETER RESULTS.

Test number.	Speed: miles per hour.	Engine No. 212, XB/1/RO.								Engine No. 213, XB/1.								Calculated stress (compression positive, tension negative): tons per square inch.	Calculated impact: per cent.
		Maximum stress recorded in right-hand compression flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in right-hand tension flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in left-hand compression flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in left-hand tension flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in right-hand compression flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in right-hand tension flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in left-hand compression flange: tons per square inch.	Corresponding impact: per cent.	Maximum stress recorded in left-hand tension flange: tons per square inch.	Corresponding impact: per cent.		
										12-Foot Span: Bridge No. 385.									
	Slow	—	—	1·1	—	—	—	1·1	—	—	—	1·1	—	—	—	1·1	—	+ 2·09 − 2·34	—
1	55	—	—	1·5	36·4	—	—	—	—	—	—	1·5	36·4	—	—	—	—	—	
2	57	—	—	1·5	36·4	—	—	·6	45·4	—	—	1·8	63·7	—	—	1·8	63·7	+ 4·18	
3	60	—	—	1·4	27·3	—	—	1·7	54·5	—	—	1·6	54·5	—	—	1·8	63·7	− 4·68	100·0
4	60	—	—	1·7	54·5	—	—	1·5	36·4	—	—	1·7	63·7	—	—	1·7	54·5		
										15-Foot Span: Bridge No. 348.									
	Slow	—	—	1·8	—	—	—	1·6	—	—	—	1·8	—	—	—	1·6	—	+ 2·5 − 2·95	—
1	65	—	—	2·2	22·2	—	—	2·0	25·0	—	—	2·2	22·2	—	—	2·5	56·2	+ 5·0 − 5·90	100·0
										30-Foot Span: Bridge No. 347A.									
	Slow	2·8*	—	—	—	2·8	—	—	—	2·8*	—	—	—	2·8	—	2·5	—	+ 2·95 − 3·11	—
1	57	3·1	10·7	—	—	—	—	2·9	16·0	3·4	21·4	—	—	—	—	3·2	28·0		
2	60	3·1	10·7	—	—	2·9	3·6	2·8	12·0	3·4	21·4	—	—	3·4	21·4	3·6	44·0	+ 5·45	84·7
3	57	3·0	7·1	—	—	3·4	21·4	3·2	28·0	3·4	21·4	—	—	3·3	17·9	3·3	32·0	− 5·74	
4	63	3·6	28·6			3·8	35·7	3·8	52·0	3·9	39·3			3·8	35·7	3·6	44·0		
										50-Foot Span: Bridge No. 183.									
	Slow	—	—	—	—	1·3	—	1·1	—	—	—	—	—	1·3	—	1·1	—	+ 2·16 − 2·41	—
1	55	—	—	—	—	1·7	30·8	—	—	—	—	—	—	1·9	46·2	—	—	+ 3·60	
2	60	—	—	—	—	2·0	53·8	—	—	—	—	—	—	2·2	69·2	—	—		
3	57	—	—	—	—	—	—	1·6	45·5	—	—	—	—	—	—	1·6	45·5		66·7
4	60	—	—	—	—	1·8	38·5	1·5	36·4	—	—	—	—	2·0	53·8	1·7	54·5	− 4·02	
										64-Foot Span: Bridge No. 393.									
	Slow	2·65	—	1·5	—	2·05	—	1·85	—	2·65	—	1·5	—	2·05	—	1·85	—	+ 2·15 − 2·62	—
1	57	3·1	17·0	1·6	6·7	2·4	17·1	2·1	13·5	3·8	43·4	1·9	26·7	3·0	46·7	2·3	24·3	+ 3·39	
2	60	3·1	17·0	1·8	20·0	2·4	17·1	2·1	13·5	3·7	39·6	2·2	46·7	2·9	41·5	2·4	29·7		57·8
3	60	3·4	28·3	1·8	20·0	2·4	17·1	2·1	13·5	3·5	32·1	2·1	40·0	2·9	41·5	2·4	29·7	− 4·13	
4	60	3·1	17·0	1·9	26·7	2·6	26·8	2·1	13·5	3·8	43·4	2·2	46·7	2·9	41·5	2·4	29·7		
										Engine No. 214.—XB/1/RO. 131-*Foot Span: Bridge No.* 688.									
	Slow	1·1	—	—	—	1·1	—	1·1	—	1·1	—	—	—	1·1	—	1·1	—	+2·4	—
1	40	1·1	nil	—	—	1·2	9·1	1·1	nil	1·4	27·3	—	—	1·3	18·2	1·2	9·1	—	—
2	30	1·1	nil	—	—	1·2	9·1	1·2	9·1	1·3	18·2	—	—	1·2	9·1	1·3	18·2	—	—
3	30	1·2	9·1	—	—	1·3	18·2	1·2	9·1	1·3	18·2	—	—	1·3	18·2	1·3	18·2	—	—
4	40	1·2	9·1	—	—	1·3	18·2	1·2	9·1	1·3	18·2	—	—	1·4	27·3	1·4	27·3	—	—
5	40	1·2	9·1	—	—	1·3	18·2	1·3	18·2	1·3	18·2	—	—	1·4	27·3	1·5	36·4	—	—
6	60	1·3	18·2	—	—	1·2	9·1	1·3	18·2	1·3	18·2	—	—	1·6	45·5	1·5	36·4	+3·3	35·9
7	57	1·3	18·2	—	—	1·3	18·2	1·5	36·4	1·4	27·3	—	—	1·6	45·5	1·6	45·5		

* Assumed value.

Figs. 7.



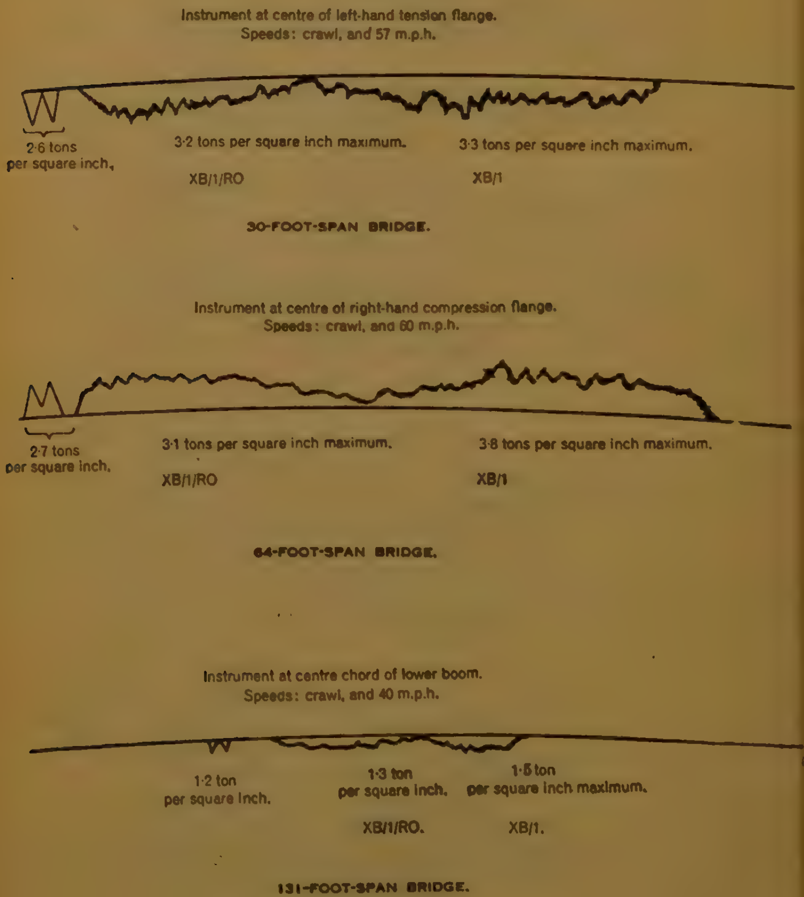
Deflectometer Records,
Vertical Scale Full Size.

were coupled between the engines, and engine No. 214, "XB/1/RO", was used instead of No. 212.

Deflexions and stresses were first measured at the crawl while the train was backing at about 3 miles per hour, and again as nearly as possible at

60 miles per hour, at which speed several runs were made. In the case of the 131-foot-span bridge, lower speeds were also run to try to obtain resonance, which was calculated to be at 3·77 revolutions per second,

Figs. 8.



SELECTED EXTENSOMETER RECORDS.

corresponding to 49 miles per hour. This was deduced from the formula [1]

$$n_0 = \frac{1}{\sqrt{\frac{w+p}{p} \cdot d}}$$

[1] Technical Paper No. 247. First and Second Interim Reports of the Bridge Sub-Committee, 1925. Indian Railway Board (1926), p. 26.

Tables II and III (facing pp. 208 and 209, *ante*) and *Figs.* 7 and 8 show the maximum recorded deflexions and stresses with percentage impacts, and Table IV, summarizes the results on spans of different lengths.

TABLE IV.—SUMMARY OF RESULTS OF BRIDGE-TESTS.

		Deflectometer results.		Extensometer results.	
		XB/1/RO.	XB/1.	XB/1/RO.	XB/1.
12′.0″ Span (Bridge No. 385).					
Maximum recorded impact :	per cent.	20·0	20·0	54·5	63·7
Average maximum impact :	,, ,,	14·3	20·0	41·6	57·2
Calculated maximum impact :	,, ,,	—	100·0	—	100·0
15′.9″ Span (Bridge No. 348).					
Maximum recorded impact :	per cent.	20·0	30·0	25·0	56·2
Average maximum impact :	,, ,,	10·3	17·4	23·6	39·2
Calculated maximum impact :	,, ,,	—	100·0	—	100·0
20′.3″ Span (Bridge No. 184).					
Maximum recorded impact :	per cent.	45·5	72·7	—	—
Average maximum impact :	,, ,,	34·1	47·8	—	—
Calculated maximum impact :	,, ,,	—	96·6	—	—
30′.0″ Span (Bridge No. 347A).					
Maximum recorded impact :	per cent.	25·0	40·0	52·0	44·0
Average maximum impact :	,, ,,	12·9	25·9	20·5	29·7
Calculated maximum impact :	,, ,,	—	84·7	—	84·7
50′.0″ Span (Bridge No. 183).					
Maximum recorded impact :	per cent.	23·8	38·1	53·8	69·2
Average maximum impact :	,, ,,	19·7	26·6	41·0	53·8
Calculated maximum impact :	,, ,,	—	66·7	—	66·7
64′.0″ Span (Bridge No. 393).					
Maximum recorded impact :	per cent.	8·0	24·0	28·3	46·7
Average maximum impact :	,, ,,	6·5	17·0	17·8	37·7
Calculated maximum impact :	,, ,,	—	57·8	—	57·8
131′.0″ Span (Bridge No. 688).					
Maximum impact :	per cent.	4·6	11·6	36·4	45·5
Average maximum impact :	,, ,,	1·97	8·9	12·5	25·1
Calculated maximum impact :	,, ,,	—	35·9	—	35·9

In the shorter spans, the deflexions are so small that impacts can be regarded as only very approximate. A difference in reading of 0·01 inch is liable to alter the impact by from 20 to 30 per cent. Similarly, small stresses were measured in some bridges, and a difference of 0·1 ton per square inch might alter the value of the impact by from 20 to 30 per

cent. Caution, therefore, should be used in interpreting the results. In the larger spans—64 feet and 131 feet—there is, in both the deflexion and the stress records, a very marked resonance effect under the "XB/1" engine which is not noticeable under the "XB/1/RO" engine. Reference to the reproduction of typical deflexion records (*Figs.* 7) brings out this difference clearly. Actual resonance was not attained in either bridge, because in the 64-foot span, 80 miles per hour was a speed too high to attain, whilst in the 131-foot span, unfortunately, no runs were made at 49 miles per hour, the calculated critical speed. The difference is, however, sufficiently striking to show the relief afforded to bridges by rebalancing for no reciprocating parts.

These results were considered by the Bridge Standards Committee at their nineteenth meeting, held in Delhi in January 1939. The Committee recommended that, when considering stress imposed by locomotives with no reciprocating parts balanced, on existing bridges, impact should be taken as 80 per cent. of the usual allowance [1, 2]. The Committee also commented on the importance of the subject from the points of view of both the bridge and the track.

Conclusion.

It is perhaps advisable to discount in advance the effect of certain remarks [3] made by the Committee sent to India in 1938 to investigate defects in the "Pacific"-type locomotives. This committee visited the Madras and Southern Mahratta Railway and recorded their opinion of two "RO" engines as follows :—"Reciprocating weights had been unbalanced and there was, as a result, fore-and-aft vibration" and "owing to the absence of balance of reciprocating parts it was very rough and there was much vibration with short-period nosing and shuttling." If there is one thing certain about a locomotive, it is that it is exceedingly difficult to isolate the effect of one feature of the engine, because there are so many effects which may mask or modify it. This is doubly or trebly true when experience is limited to one comparatively short run on the locomotive. The Authors are therefore frankly surprised that the committee sponsored on such limited experience the statement that rough riding in those cases was due to lack of overbalance, especially in view of an opinion recorded later in the Report in regard to certain modifications made in "XB" locomotives, that "their effect could be evaluated in no better way than by personal impression gained when riding on the footplate on various occasions, without regard to time or place, and this

[1] Bridge Rules (1933). Indian Railway Board.

[2] British Standard Specification for Girder Bridges, No. 153, Parts 3, 4 & 5 (1937), Appendix 2.

[3] Pacific Locomotive Committee Report, 1939. Government of India Publications, Delhi.

can be very misleading." Against these two adverse criticisms, based, in the opinion of the Authors, on wholly inadequate experience, there is the fact that seventy-five "RO" locomotives are in daily use on the Madras and Southern Mahratta Railway. No trouble has been experienced which can be connected in any way with the lack of overbalance, and the chief mechanical engineer is satisfied that no difference can be detected between these engines and engines normally balanced, either in wear-and-tear or in behaviour on the road. It is admitted that the experience has been gained with outside-cylinder locomotives at what some railways may consider comparatively low speeds. There is nothing to show, however, that the results would have been different had higher speeds and other types of locomotives been under consideration.

A good deal has been written and said about locomotive balancing in recent years, and it might be contended that the subject may now be allowed to drop. The Authors, however, are of the opinion that this is a mistaken view, and that the subject is of increasing importance. There has been a widespread move to increase railway-speeds in most countries and there are already indications that this will introduce new troubles. In America it has been discovered that, with certain locomotives at very high speeds, the main driving-wheel actually lifts clear of the rail at one point in its revolution. Apart from any risk of derailment entailed, this must increase rail and bridge stresses to dangerously near to, or even beyond, the safe limit. The Authors' view is, therefore, that a *prima facie* case for abolishing overbalance has been established, and that if locomotive engineers wish to continue this practice, they must prove that it is necessary. It is certainly expensive.

The Authors are indebted to the Administration of the Madras and Southern Mahratta Railway for permission to present this Paper. They also wish to express their thanks to Mr. R. Lean, chief mechanical engineer of the Madras and Southern Mahratta Railway, for his co-operation and help, and to Mr. D. H. McPherson, B.Sc., Assoc. M. Inst. C.E., who carried out the experimental work on the impact effects on bridges.

The Paper is accompanied by twenty-six sheets of drawings, from some of which Plates 1 and 2 and the Figures in the text have been prepared, and by four Appendixes, two of which have been reproduced.

APPENDIX I.

PRINCIPAL BALANCING DATA AND CALCULATIONS FOR HAMMER-BLOW OF A NORMALLY-BALANCED XB/1 CLASS ENGINE.

DRIVING-WHEELS.

DATA.

Stroke	28	inches.
Centres of return-cranks	103·5	,,
,, ,, cylinders	94·5	,,
,, ,, coupling-rods	82·0	,,
,, ,, balance-weights	70·5	,,
,, ,, wheel-cranks	69·75	,,

Reciprocating mass per cylinder, consisting of piston, rings, rods, cross-head, slides, pin, etc., complete, and proportion of connecting-rod = 843 lb.

Revolving Masses.

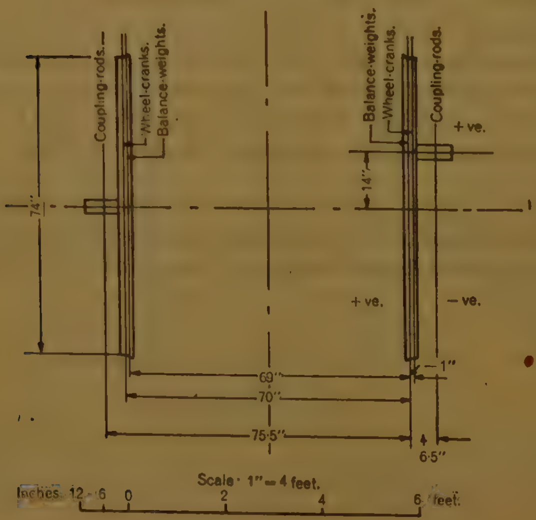
Unbalanced mass of each return-crank (⅔ proportion) = 52 lb.

Unbalanced mass at connecting-rod pin, consisting of proportion of rod and part pin = 309 lb. + 57 lb. = 366 lb.

Unbalanced mass of coupling-rod pin, consisting of proportion of rod and part pin = 260·8 lb. + 68·2 lb. = 329 lb.

Unbalanced mass of each balance-weight reduced to 14-inch radius = 1,326 lb.

Unbalanced mass of each wheel crank and part pin reduced to 14-inch radius = 254 lb.



Leading and Trailing Coupled Wheels.

Data.

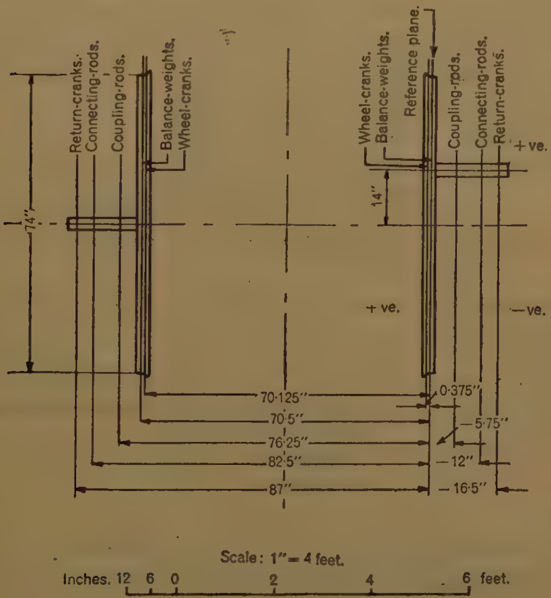
Stroke	28 inches.
Centres of coupling-rods	82·0 ,,
Centres of wheel-cranks	71·0 ,,
Centres of balance-weights	69·0 ,,
Reciprocating mass per cylinder	843 lb.

Revolving masses.

Unbalanced mass at coupling-rod pin = 126 lb.

Unbalanced mass of each wheel-crank and part pin reduced to 14-inch radius = 210 lb.

Unbalanced mass of each balance-weight reduced to 14-inch radius = 574 lb.



Driving-wheels. (Revolving masses only.)

Note :—The centre-line of the left-hand balance-weight crescent makes an angle θ_1 with the horizontal, such that $\tan \theta_1 = \frac{1}{10\cdot 03}$.

Splitting up the left-hand balance-weight into horizontal and vertical components;

the left-hand horizontal mass $= M_1 \cos \theta_1 = 1326 \times \frac{10\cdot 03}{10\cdot 08} = 1319\cdot 4$ lb.; and

,, ,, ,, vertical ,, $= M_1 \sin \theta_1 = 1326 \times \frac{1}{10\cdot 08} = 131\cdot 5$ lb.

If a denote the angle made by the resultant moment R_1 with the horizontal,

$$\text{then } \tan a = \frac{2224\cdot 2}{15{,}401}$$

$$\text{and } a = 8^\circ\ 13'$$

$$\text{Hence } R_1 = 15{,}401 \sec 8^\circ\ 13' = 15{,}560\cdot 8 \text{ lb.-inches.}$$

Particulars.	x component, + *ve*. $\rightarrow$			y component, + *ve* $\uparrow$.		
	Mass : lb.	Arm : inches.	Moment : lb.-inches.	Mass : lb.	Arm : inches.	Moment : lb.-inches.
Right-hand return crank	—	—	—	+ 52·0	− 16·5	− 858·0
Right-hand connecting-rod	—	—	—	+ 366·0	− 12·0	− 4,392·0
Right-hand coupling-rod	—	—	—	+ 329·0	− 5·75	− 1,891·8
Right-hand balance-weight (vertical) . .	—	—	—	—	—	—
Right-hand balance-weight (horizontal) .	—	—	—	—	—	—
Right-hand wheel-crank	—	—	—	+ 254·0	+ 0·375	+ 95·3
Left-hand wheel-crank .	+ 254·0	+ 70·125	+ 17,812	—	—	—
Left-hand balance-weight (vertical)	—	—	—	+ 131·5	+ 70·5	+ 9,270·7
Left-hand balance-weight (horizontal) . . .	−1,319·4	+ 70·5	− 93,018	—	—	—
Left-hand coupling-rod .	+ 329·0	+ 76·25	+ 25,086	—	—	—
Left-hand connecting-rod	+ 366·0	+ 82·5	+ 30,195	—	—	—
Left-hand return-rod .	+ 52·0	+ 87·0	+ 4,524	—	—	—
	− 318·4	—	− 15,401	+ 1,132·5	—	+ 2,224·2

The out-of-balance mass at 14 inches $= \frac{15{,}560 \cdot 8}{70 \cdot 5} = 220 \cdot 72$ lb., whence the out-of-balance moment $= 220 \cdot 72 \times 14 = 3{,}090 \cdot 1$ lb.-inches.

The hammer-blow in tons $= Mr \times \frac{4\pi^2}{g} \times n^2$, where M denotes the mass in tons, r denotes the lever-arm in feet, and n denotes the number of revolutions per second.

$$\text{Therefore the hammer-blow} = \frac{3090 \cdot 1 \times 4\pi^2}{2240 \times 12} \times \frac{n^2}{32 \cdot 2}$$
$$= 0 \cdot 14094\ n^2$$

Leading and trailing coupled-wheels. (Both wheels are similar.)

Note :—The centre-line of the left-hand balance-weight crescent makes an angle θ_2 with the horizontal, such that $\tan \theta_2 = \frac{1}{11 \cdot 64}$.

Splitting up the left-hand balance-weight into horizontal and vertical components the left-hand horizontal mass $= M_2 \cos \theta_2 = 574 \times \frac{11 \cdot 64}{11 \cdot 684} = 571 \cdot 89$ lb., and

,, ,, ,, vertical ,, $= M_2 \sin \theta_2 = 574 \times \frac{1}{11 \cdot 684} = 49 \cdot 13$ lb.

If β denote the angle made by the resultant moment R_2 with the horizontal,

$$\text{then } \tan \beta = \frac{2361}{15{,}247} = 0 \cdot 15488$$
$$\text{and } \beta = 8^\circ\ 48'$$
$$\text{Hence } R_2 = 15{,}247 \sec 8^\circ\ 48' = 15{,}428 \cdot 6 \text{ lb.-inches.}$$

The out-of-balance mass at 14 inches $= \frac{15{,}428 \cdot 6}{69} = 223 \cdot 6$ lb., whence the out-of-balance moment $= 223 \cdot 6 \times 14 = 3130 \cdot 4$ lb.-inches.

Particulars.	x component, $+ ve \rightarrow$			y component, $+ ve \uparrow$.		
	Mass: lb.	Arm: inches.	Moment: lb.-inches.	Mass: lb.	Arm: inches.	Moment: lb.-inches.
Right-hand coupling-rod .	—	—	—	+ 126·0	− 6·5	− 819
Right-hand wheel-crank .	—	—	—	+ 210·0	− 1·0	− 210
Right-hand balance-weight (vertical)	—	—	—	—	—	—
Right-hand balance-weight (horizontal)	—	—	—	—	—	—
Left-hand balance-weight (vertical)	—	—	—	+ 49·13	+ 69·0	+ 3,390
Left-hand balance-weight (horizontal)	− 571·89	+ 69·0	− 39,460	—	—	—
Left-hand wheel-crank .	+ 210·0	+ 70·0	+ 14,700	—	—	—
Left-hand coupling rod .	+ 126·0	+ 75·5	+ 9,513	—	—	—
	− 235·89	—	− 15,247	+ 385·13	—	+ 2,361

$$\text{Therefore the hammer-blow in tons} = Mr \times \frac{4\pi^2}{g} \times n^2$$

$$\doteqdot \frac{3130{\cdot}4 \times 4\pi^2 n^2}{2240 \times 12 \times 32{\cdot}2}$$

$$= 0{\cdot}14278\, n^2$$

Values of n *and* n².

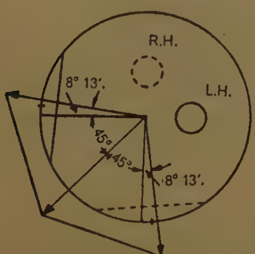
Maximum speed = 74 miles per hour;
Diameter of driving-wheels = 74 inches;

$$\text{whence } n = \frac{74 \times \frac{88}{60}}{6{\cdot}166 \times \pi} = 5{\cdot}602.$$

$$n^2 = 31{\cdot}385.$$

Calculation of P_1, the Engine Hammer-Blow (Both Sides Combined) at 1 Revolution per Second.

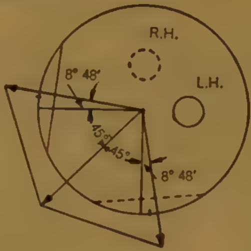
Driving-wheel.



Axle hammer-blow = 2 × wheel hammer-blow × cos ϕ_1, where $\phi_1 = 45° + 8° 13'$ $= 53° 13'$; cos $\phi_1 = 0{\cdot}5988$.

Hence axle hammer-blow = 2 × 0·14094 × 0·5988 = 0·16879 tons.

Leading and trailing coupled-wheels.



$$\phi_2 = 45° + 8°\ 48' = 53°\ 48' : \cos\phi_2 = 0{\cdot}5906.$$

Hence axle hammer-blow $= 2 \times 0{\cdot}14278 \times 0{\cdot}5906 = 0{\cdot}16866$ tons.

As these both act in the same direction, they may be added numerically. Hence $P_1 = 0{\cdot}16866$ ton (leading coupled-wheel axle) $+ 0{\cdot}16879$ ton (driving-wheel axle) $+ 0{\cdot}16866$ ton (trailing coupled-wheel axle) $= 0{\cdot}50611$ ton.

The engine hammer-blow at 5·6 revolutions per second = hammer-blow at 1 revolution per second $\times n^2$;

whence hammer-blow at 5·6 revolutions per second of leading coupled-wheels
$= 0{\cdot}16866 \times 31{\cdot}385 = 5{\cdot}2934$ tons.

hammer-blow at 5·6 revolutions per second of driving-wheels
$= 0{\cdot}16879 \times 31{\cdot}385 = 5{\cdot}2975$ tons.

hammer-blow at 5·6 revolutions per second of trailing coupled-wheels
$= 0{\cdot}16866 \times 31{\cdot}85 = 5{\cdot}2934$ tons.

Hence hammer-blow at 5·6 revolutions per second for the engine = 15·8843 tons.

APPENDIX II.

Impact Effects on Railway-Bridges.

The following formulas [1] appear in Appendix II of British Standard Specification No. 153 [2].

(*a*) Effects due to rail-joints and track and wheel-irregularities :

$$I_A = \frac{20Kn}{(l + 20)U},$$

where I_A denotes the impact factor, K is a constant taken as 1·0; l denotes the effective span in feet; n denotes revolutions per second of the driving wheels, taken as 4·67 ; U denotes the number of units of B.S. Loading, taken as 15.

(*b*) Effects due to hammer-blow of reciprocating locomotives due to balancing of reciprocating parts or lack of balance of revolving parts :—

(1) For longitudinal bearers and cross-girders and for main girders up to 40-foot spans :

$$I_B = C_1\phi\frac{n^2}{l + 40}$$

[1] R. W. Foxlee and E. H. Greet, "Hammer-Blow Impact on the Main Girders of Railway-Bridges," Minutes of Proceedings, Inst. C.E., vol. 237 (1933–34), p. 239.

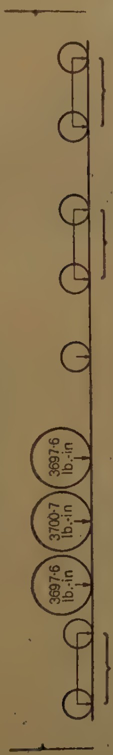
[2] British Standard Specification for Girder Bridges, No. 153, Parts 3, 4 & 5 (1937) Appendix 2.

(2) For main girders over 40 feet and up to 80-foot spans:

$$I_B = C_2 \phi \left(\frac{n^2}{36} + \frac{l - 40}{25(10P - l)} \right)$$

REPORT SHEET.

BALANCING CALCULATIONS.



Axle-loads, engine and tender empty: tons.	20·5	15·3875	15·4375	15·075	14·7625	17·2625	16·9375	Total tons 115·3625
Axle-loads, engine and tender in working order: tons.	22·05	17·00	17·025	17·075	16·95	33·888	33·425	157·413
Axle hammer-blow at 74 m.p.h.: tons.	—	5·293	5·297	5·293	—	—	—	15·883
Total axle-load at 74 m.p.h.: tons.	22·05	22·293	22·322	22·368	16·95	33·888	33·425	173·296

5′ 6″-GAUGE XB/1-CLASS LOCOMOTIVE.

(3) For main girders over 80 feet and up to 300-foot spans:

$$\left.\begin{array}{l} I_B = \text{Formula (2) above or} \\ I_B = C_2 \phi \dfrac{30 \quad (50P + 3l)}{(10P - 1)(l + 70)} \end{array}\right\} \text{whichever is the smaller,}$$

where I_B denotes the impact factor,

n ,, revolutions per second of the driving wheels, taken as 4·67, ($n^2 = 21{\cdot}81$),

P ,, hammer-blow in tons of the whole locomotive at 1 revolution per second of the driving-wheels, but with a minimum of 0·2 ton, taken as 0·504 for "XB/1" and 0·2 for "XB/1/RO,"

U ,, number of units of B.S. Loading, taken as 15.

$$\phi = \frac{25\,P}{U} = 0{\cdot}840 \text{ for "XB/1,"}$$

$$= 0{\cdot}333 \text{ for "XB/1/RO,"}$$

$C_1 = 1{\cdot}25$ for main girders directly supporting one rail,

$C_2 = 0{\cdot}45$ for main girders of single-track bridges,

l = effective span in feet.

The impact factors for three bridges tested under "XB/1" and "XB/1/RO" have been worked out and compared with the impacts obtained from deflectometer and extensometer results in Table V.

TABLE V.

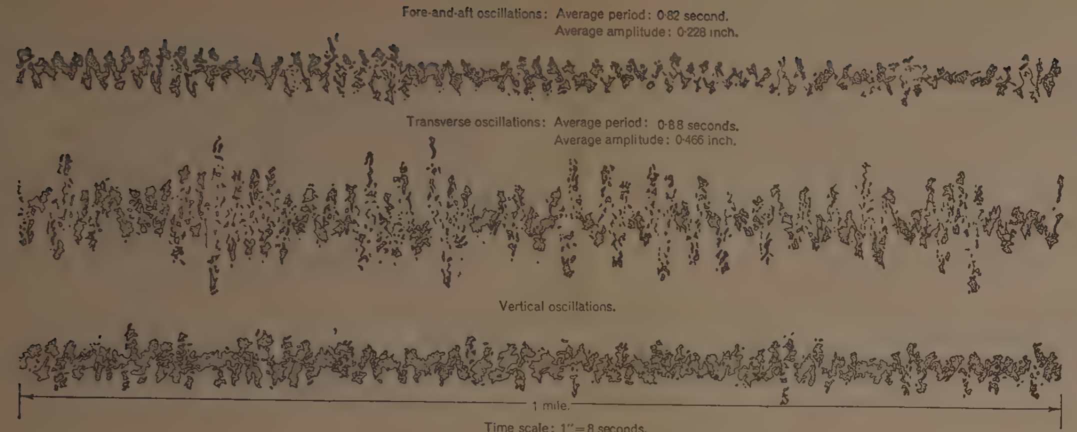
Nominal span : feet. . . Effective span : feet. . .	30 31·75		64 67·75		131 136·0	
	XB/1/RO.	XB/1.	XB/1/RO.	XB/1.	XB/1/RO.	XB/1.
I_A	12·0	12·0	7·1	7·1	3·80	3·80
I_B	12·7	31·9	25·8	33·3	23·6	38·6
$I_A + I_B$ . .	24·7	43·9	32·9	40·4	27·40	42·40
Maximum impact by deflectometer	25·0	40·0	8·0	24·0	4·6	11·6
Average impact by extensometer	20·0	29·7	17·8	37·7	12·5	25·1

It is clear that the minimum value for P specified for the "RO" engine (0·2) is too high in the case of the 64-foot and 131-foot spans, where the measured impact is noticeably less than that derived from the formulas.

HAMMER-BLOW IN LOCOMOTIVES: CAN IT NOT BE ABOLISHED ALTOGETHER?

Figs. 2.

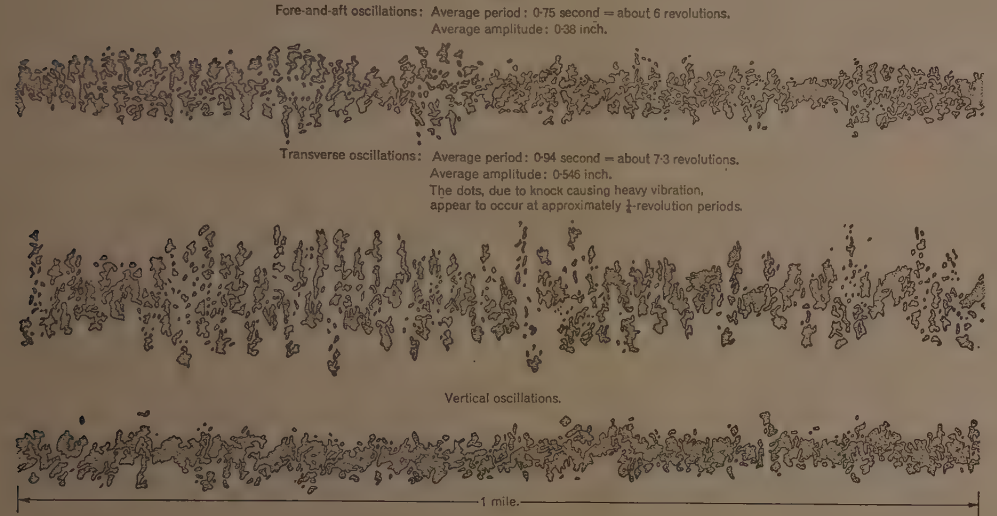
(a).



Time scale: 1″ = 8 seconds.
Average speed: 76 miles per hour.

TWO-THIRDS OF THE RECIPROCATING PARTS BALANCED.

(b).



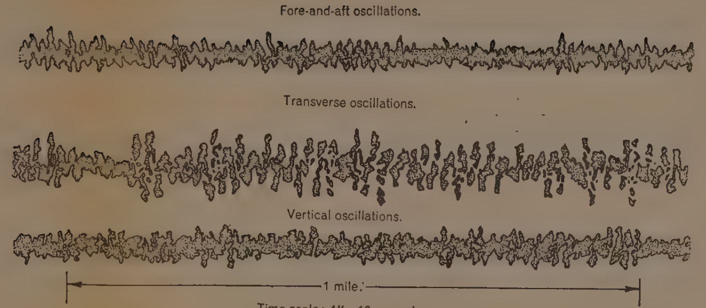
Time scale: 1″ = 8 seconds.
Average speed: 79 miles per hour.

RECIPROCATING PARTS UNBALANCED.

HALLADE TRACK-RECORDS FOR "XB" CLASS LOCOMOTIVES.

Figs. 3.

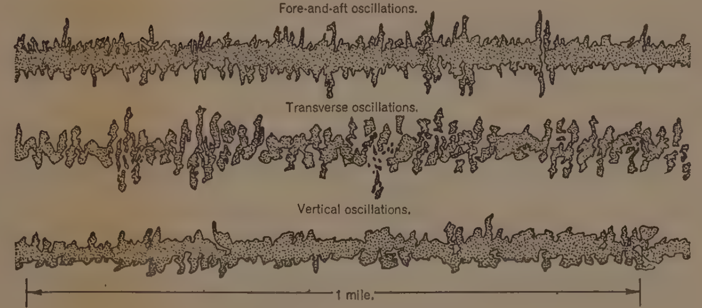
(a).



Time scale: 1″ = 16 seconds.
Average speed: 65½ miles per hour.

ENGINE XB 203, RECIPROCATING PARTS UNBALANCED.
This engine is fitted with "Ferodo" lining on the bogie slides, to Central Standards Office design.

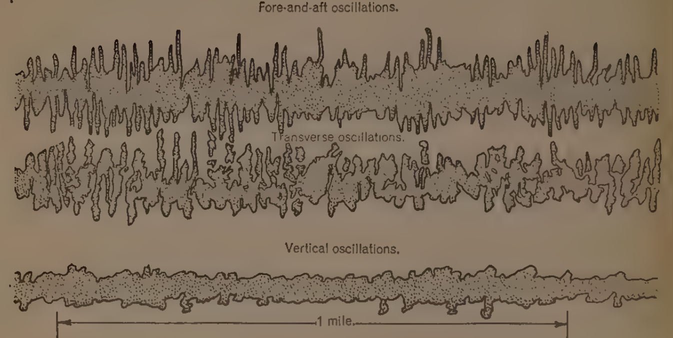
(b).



Time scale: 1″ = 16 seconds.
Average speed: 61 miles per hour.

ENGINE XB 209, NORMALLY BALANCED.
This engine is fitted with "Ferodo" lining on the bogie slides, to Central Standards Office design.

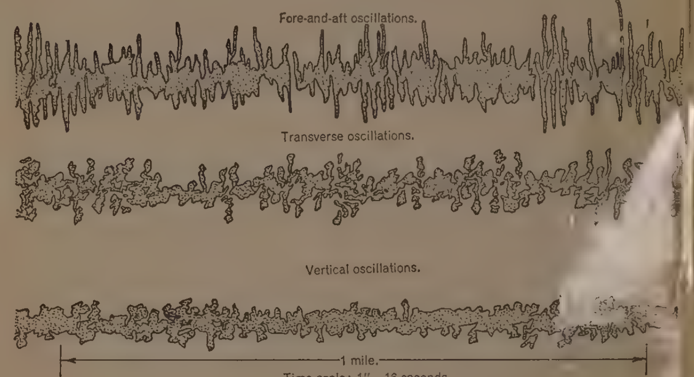
(c).



Time scale: 1″ = 16 seconds.
Average speed: 73 miles per hour.

ENGINE XB 212, RECIPROCATING PARTS UNBALANCED.
This engine is fitted with "American" draw-gear, to Central Standards Office design.

(d).



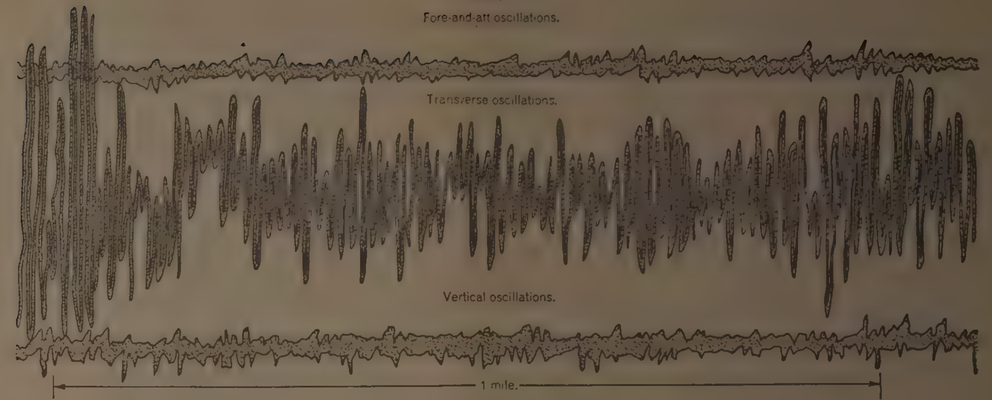
Time scale: 1″ = 16 seconds.
Average speed: 63½ miles per hour.

ENGINE XB 222, NORMALLY BALANCED.
This engine is fitted with "Ferodo" lining on the bogie slides, to Central Standards Office design.

HALLADE TRACK-RECORDS FOR "XB" CLASS LOCOMOTIVES.

Figs. 4.

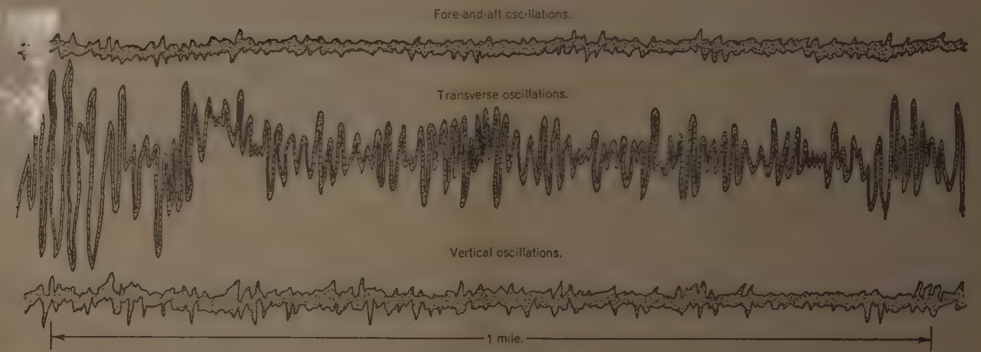
(a)



Time scale: 1″ = 16 seconds.
Average speed: 45 miles per hour.

ENGINE YC 555, NORMALLY BALANCED.
This engine is fitted with flat hind-truck slides with "Ferodo," to Central Standards Office design.

(b)



Time scale: 1″ = 16 seconds.
Average speed: 42·3 miles per hour.

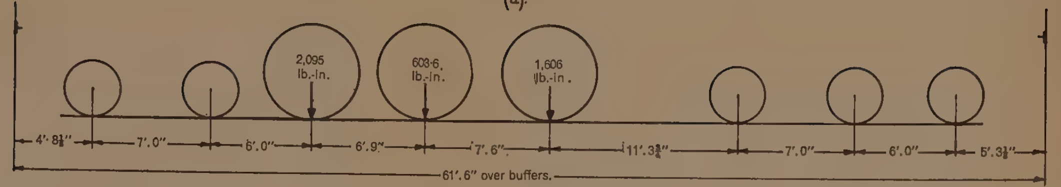
ENGINE YC 559, RECIPROCATING PARTS UNBALANCED.

HALLADE TRACK-RECORDS FOR "YC" CLASS LOCOMOTIVES.

William Clowes & Sons, Limited: London.

SIR HAROLD N. COLAM AND MAJOR J. D. WATSON,

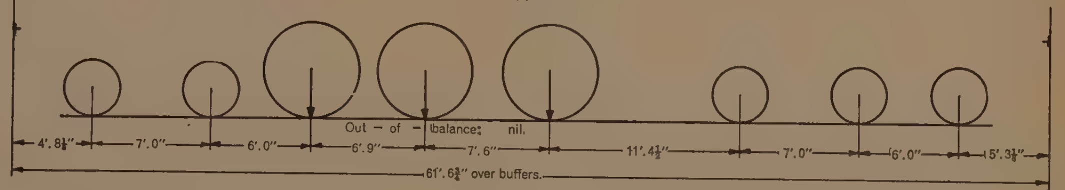
(a).



Static axle-load: tons.	10·475	10·475	17·5	17·5	17·5	15·95	16·15	16·0	Total tons: 121·55
Axle hammer-blow at maximum speed (74 m.p.h. = 5·6 r.p.s.): tons.			2·999	0·864	2·299				
Total axle-load at maximum speed: tons.			20·499	18·364	19·799				
Maximum axle-load: tons.			20·499						
P_1 = 0·196.									

BROAD-GAUGE "W.B.C. $\frac{A}{S}$" CLASS ENGINES.

(b).

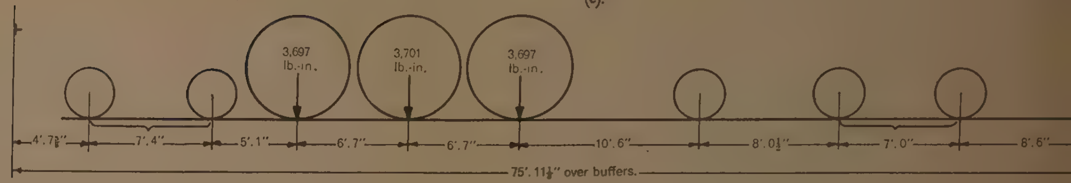


Static axle-load: tons.	10·75	10·75	18·0	18·0	18·0	16·75	16·80	16·8	Total tons: 125·85.
Axle hammer-blow at maximum speed: tons.			Nil.	Nil.	Nil.				
Total axle-load at maximum speed: tons.			18·0	18·0	18·0				
Maximum axle-load: tons.				18·0					
P_1 = 0	Reciprocating parts unbalanced.								

BROAD-GAUGE "W.B.C./RO" CLASS ENGINES.

William Clowes & Sons, Limited: London

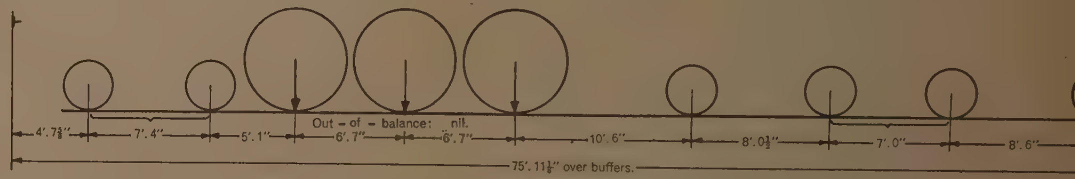
(c).



Static axle-load: tons.	22·05	17·0	17·025	17·075	16·95	33·888
Axle hammer-blow at maximum speed (74 m.p.h. = 5·6 r.p.s.): tons.		5·292	5·295	5·292		
Total axle-load at maximum speed: tons.		22·292	22·320	22·367		
Maximum axle-load: tons.				22·367		
P_1 = 0·5						

BROAD-GAUGE "XB/A" CLASS ENGINES.

(d).

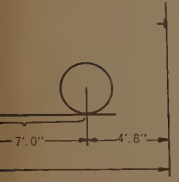


Static axle-load: tons.	24·85	17·0	17·0	17·0	16·9	33·8875
Axle hammer-blow at maximum speed (74 m.p.h. = 5·6 r.p.s.): tons.		Nil.	Nil.	Nil.		
Total axle-load at maximum speed: tons		17·0	17·0	17·0		
Maximum axle-load: tons.			17·0			
P_1 = 0	Reciprocating parts unbalanced.					

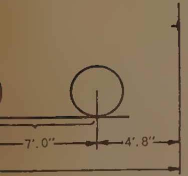
BROAD-GAUGE "XB/RO" CLASS ENGINES.

…T NOT BE ABOLISHED ALTOGETHER?

FIGS. 6.

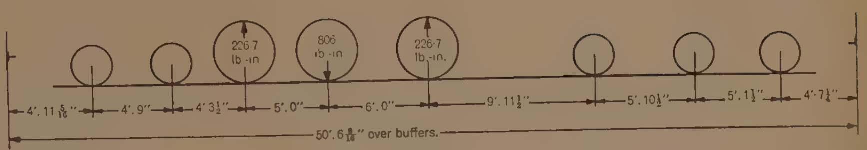


33·425	Total tons: 157·412.



33·425	Total tons: 160·06

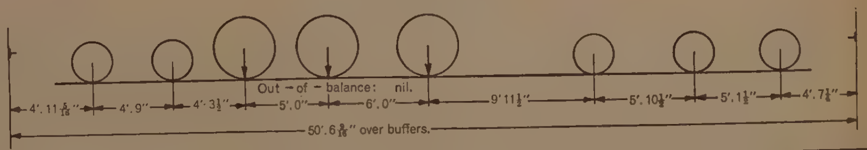
(e).



Static axle-load: tons.	3·80	3·80	7·95	8·0	8·0	7·85	7·675	7·625	Total tons: 54·70.
Axle hammer-blow at maximum speed (57 m.p.h. = 5·6 r.p.s.): tons.			– 0·323	+ 1·155	– 0·323.				
Total axle-load at maximum speed: tons.			7·627	9·155	7·677				
Maximum axle-load: tons.				9·155					
P_1 = 0·0162									

METRE-GAUGE "P/1A" CLASS ENGINES.

(f).



Static axle-load tons.	4·25	4·20	8·10	8·10	8·05	7·45	7·375	7·325	Total tons: 54·85.
Axle hammer-blow at maximum speed: tons.			Nil.	Nil.	Nil.				
Total axle-load at maximum speed: tons.			8·10	8·10	8·05				
Maximum axle-load: tons.				8·10					
P_1 = 0.	Reciprocating parts unbalanced.								

METRE-GAUGE "PS1/RO" CLASS ENGINES.

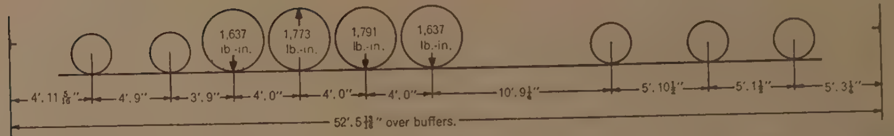
BALANCING DIAGRAMS.

Journal. January, 1942.

PLATE 2.

HAMMER-BLOW IN LOCOMOTIVES: CAN IT NOT BE ABOLISHED ALTOGETHER?

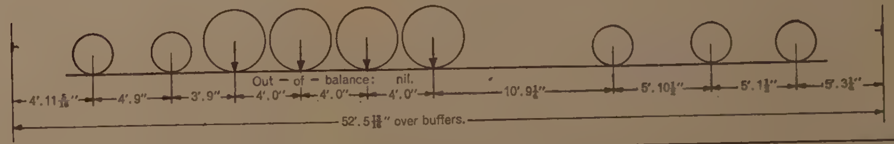
(g)



Static axle-load: tons.	3·7	3·7	8·25	8·3	8·3	8·25	8·2	8·0	7·85	Total tons: 64·55.
Axle hammer-blow at maximum speed (43 m.p.h. = 5·6 r.p.s.): tons.			2·34	– 2·54	+ 2·56	+ 2·34				
Total axle-load at maximum speed: tons.			10·59	5·76	10·86	10·59				
Maximum axle-load: tons.					10·86					
P_1 = ·145										

METRE-GAUGE "G/1-2-3A" CLASS ENGINES.

(h).



Static axle-load: tons.	4·25	4·20	8·35	8·50	8·40	8·40	8·20	8·0	7·85	Total tons: 66·15.
Axle hammer-blow at maximum speed: tons.			Nil.	Nil.	Nil.	Nil.				
Total axle-load at maximum speed: tons.			8·35	8·50	8·40	8·40				
Maximum axle-load: tons.				8·5						
P_1 = 0	Reciprocating parts unbalanced.									

METRE-GAUGE "GS1/RO" ENGINES.

SIR HAROLD N. COLAM AND MAJOR J. D. WATSON.

(2) "Balancing of Locomotive Reciprocating Parts." * †

By Ernest Stewart Cox, A.M.I.Mech.E.‡

TABLE OF CONTENTS.

Introduction.

The fundamental theory of locomotive balancing is nearly 100 years old. Nollau was the first to formulate it, in 1847, and 2 years later Le Chatelier, of the Orleans Railway, worked out its application with the help of experiments with an engine slung clear of the rails and run up to speeds of 3 revolutions per second. In Great Britain Mr. D. K. Clark, M. Inst. C.E., laid down rules based on Le Chatelier's work which have been generally followed since, and a simple graphical demonstration of this theory was made with the utmost clarity by Prof. W. E. Dalby, M. Inst. C.E., in 1901 [1]. There is little else which can be added in this respect.

In the practical application of the theory, it is universally agreed that revolving masses should be completely balanced; but there has been, and still remains, considerable divergence of opinion as to how the reciprocating masses are to be dealt with. If they are left unbalanced there is an alternating longitudinal force exerted on the frame of the engine together with a couple tending to set up nosing. If they are balanced by means of revolving weights in the wheels, the centrifugal effect of these weights sets up a variation in rail-pressure, or hammer-blow, once per revolution. Two conflicting needs have to be satisfied, namely, that of the mechanical engineer, who wishes to avoid all longitudinal and transverse disturbing forces on the locomotive itself, and that of the civil engineer, who wishes to avoid all hammer-blow effects on rails and bridges.

---

* Published by permission of the Institution of Mechanical Engineers.

† Correspondence on this Paper can be accepted until the 15th April, 1942, and will be published in the Institution Journal for October, 1942.—Sec. Inst. C.E.

‡ Chief Technical Assistant to Chief Mechanical Engineer, L.M.S. Railway.

[1] "Balancing of Locomotives," Proc. Inst.Mech.E. 1901, p. 1157.

There is no doubt that unbalanced reciprocating parts caused serious disturbances on the lightweight engines of a century ago, and the mechanical engineers of that day were driven by urgent need to adopt balancing of those parts. First attempts were in the direction of two pistons acting in opposite directions in the same cylinder, but in 1845 Fernihough, of the Eastern Counties Railway, initiated the use of revolving weights to balance reciprocating parts. At first, as a reaction from the unsteady running formerly prevailing, the whole of the weights were balanced, but the development of flats on the soft iron tires of that day at the point of maximum rail-pressure called for a compromise which eventually resulted in the proportion of two-thirds which was general in British practice until quite recently.

The subject of locomotive balancing was very thoroughly investigated, as regards the vertical forces, by the British Bridge Stress Committee, whose report, published in 1928[1], drew attention to the outstanding effect of locomotive hammer-blow on stresses in bridges and to the widely varying hammer-blow characteristics of engines then running. It formulated a recommendation that all future locomotives should be designed so that at a speed of 5 revolutions per second the axle hammer-blow will not exceed one-fourth of the static load, or 5 tons as a maximum, and that the hammer-blow of the engine as a whole should not exceed 12½ tons. This has, in the main, been faithfully worked to by British railways in all new construction since that date.

No comparable investigation has been made into the effect of the horizontal forces on the locomotive itself. Moreover, since 1928 actual and potential speeds have increased considerably. Cases have become known of locomotives running apparently satisfactorily with little or no reciprocating balance, and the possibility of hammer-blow in name only becoming an alarming reality has been demonstrated by the "wheel-bouncing" experiences recorded in America. All these factors call for a reconsideration of how the balancing should be dealt with.

It is the object of this Paper to record British practice and experience affecting vertical hammer-blow observed since 1928, to examine the horizontal effect of unbalanced reciprocating masses on the locomotive itself, and to discuss the proportion of those masses which it is necessary to balance in various circumstances.

Existing British Practice.

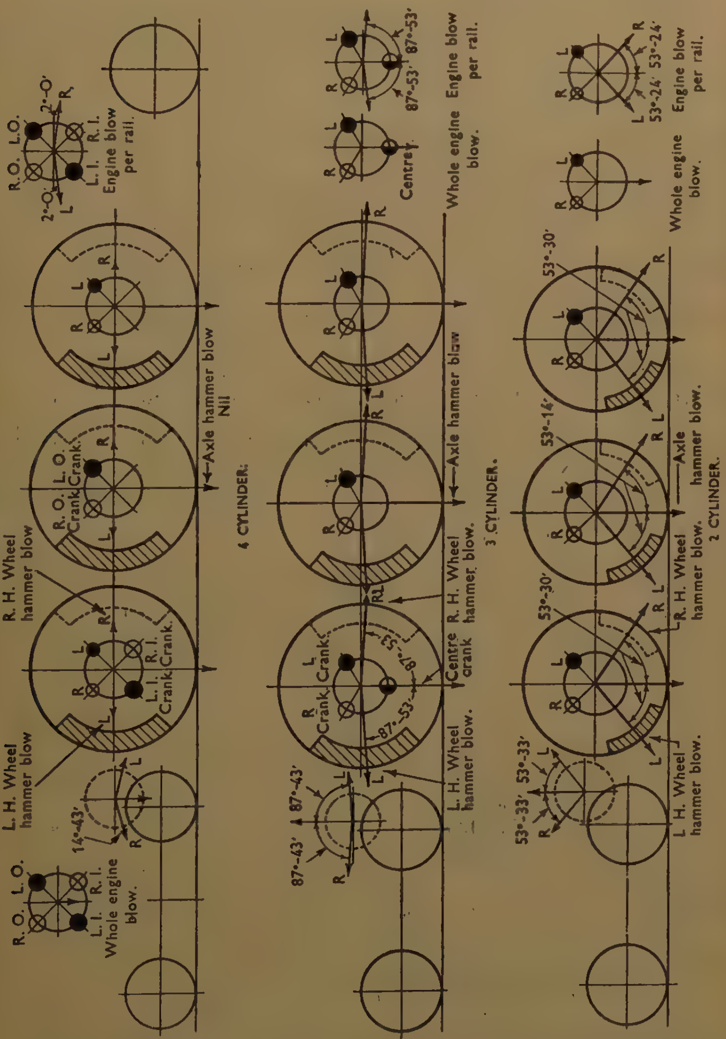
Table I sets out hammer-blow values of representative British locomotives, showing how at 5 revolutions per second they conform to the Bridge Stress Committee's recommendations. A second line for each engine gives values at 8 revolutions per second—a maximum speed of

[1] Report of the Bridge Stress Committee (Department of Scientific and Industrial Research), 1928. H.M. Stationary Office.

which most modern designs are capable. Particulars are given of the reciprocating weights and the percentage balanced ; *Figs. 1* and *2* are typical hammer-blow diagrams for two-, three-, and four-cylinder engines.

Below are comments on various aspects of present-day practice.

Figs. 1.



Typical Hammer-Blow Diagrams for Two-, Three-, and Four-Cylinder Engines, London, Midland and Scottish Railway.

Reciprocating weights balanced.—The need to keep the reciprocating weights within limiting values while the power of engines has increased has been met either by reducing the percentage of reciprocating weights balanced or by reducing the weights of the reciprocating parts themselves.

TABLE I.—HAMMER-BLOW PARTICULA

Engines.	Number of cylinders.	Reciprocating weight per cylinder.		Percentage balanced.		Speed.	
		Inside: lb.	Outside: lb.	Inside.	Outside.	r.s.p.	m.p.h
London, Midland and Scottish:							
4–6–2 Coronation . .	4	698	663	47·3	49·8	5	72
						8	115
4–6–0 Class 5X . . .	3	751	750	66·6	66·6	5	72
						8	115
4–6–0 Class 5 . . .	2	—	933	—	50*	5	64
						8	103
2–6–4T No. 2500 . .	3	716	621	66·6	66·6	5	61
						8	98
2–6–4T No. 2537 . .	2	—	733	—	66·6	5	61
						8	98
London and North Eastern:							
4–6–2 A4	3	593	517	40	40	5	71
						8	114
2–6–0 K3	3	585	533	60	60	5	61
						8	97
2–6–2T V1	3	549	508	60	60	5	61
						8	97
Great Western:							
4–6–0 King	4	594	527	34·2	41·8	5	70
						8	111
4–6–0 Hall	2	—	800	—	69·9	5	64
						8	103
2–6–2T 5101 Class . .	2	—	731	—	66·6†	5	61
						8	97
Southern:							
4–6–2 Merchant Navy .	3	764	798	Nil	Nil	5	66
						8	106
4–6–0 Lord Nelson . .	4 (cranks at 135 degrees)	533	567	40	40	5	70
						8	113
4–6–0 King Arthur . .	2	—	934	—	40	5	70
						8	113
4–4–0 School. . . .	3	606	563	30	30	5	70
						8	113

* Earlier engines of this class have 66·6 per cent. and 55 per cent.

The proportion of about two-thirds of the weight balanced has been generally adhered to until recently, although on the largest classes of multi-cylinder passenger engines on the London, Midland and Scottish, the London and North Eastern, and the Great Western railways a conservative reduction towards 40 per cent. has been made. As against this, the Great

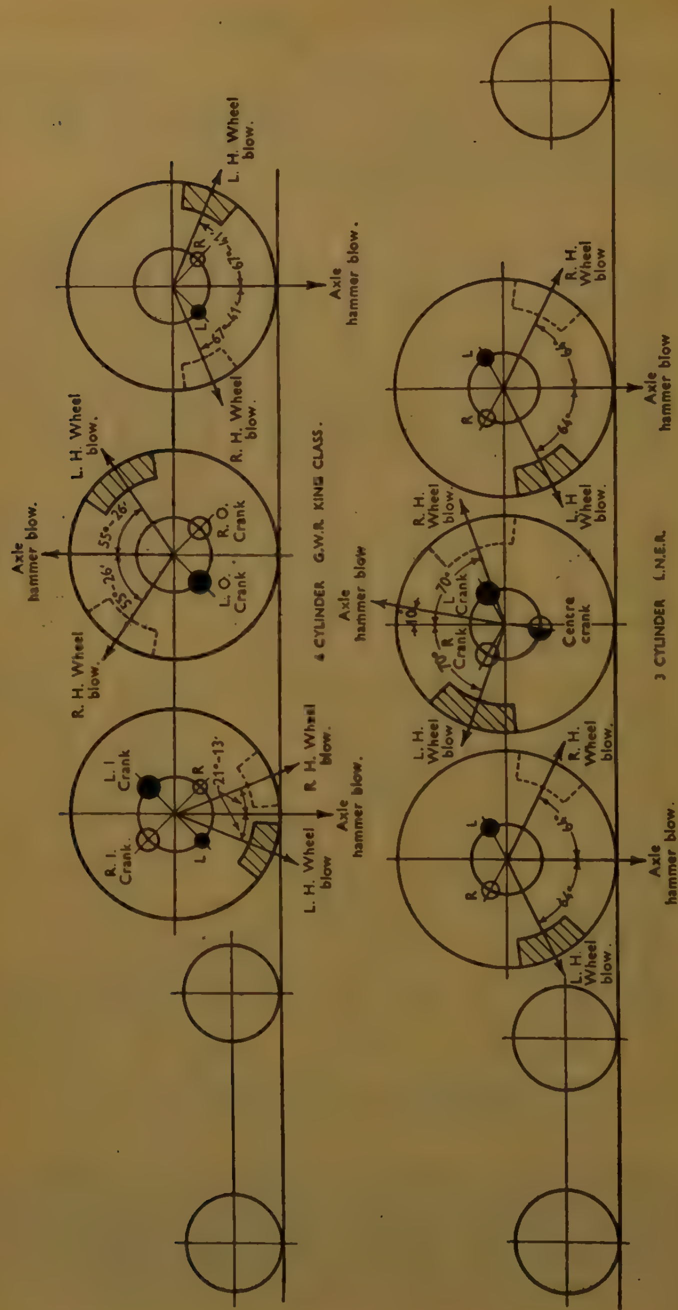
or Various Engines.

Hammer-blow. Per wheel. Leading: tons.	Hammer-blow. Per wheel. Intermediate: tons.	Hammer-blow. Per wheel. Trailing: tons.	Hammer-blow. Per axle. Leading: tons.	Hammer-blow. Per axle. Intermediate: tons.	Hammer-blow. Per axle. Trailing: tons.	Slidebar hammer-blow. On either side: tons.	Slidebar hammer-blow. Whole engine: tons.	Total hammer-blow per rail: tons.	Whole engine hammer-blow: tons.	Weight of engine in working order: lb.
1·31	1·31	1·31	Nil	Nil	Nil	0·48	0·24	3·47	0·24	242,144
3·35	3·35	3·35	Nil	Nil	Nil	1·23	0·61	8·88	0·61	
3·06	3·06	3·06	0·23	0·23	0·23	0·89	0·07	8·31	0·61	178,192
7·84	7·84	7·84	0·59	0·59	0·59	2·27	0·18	21·20	1·56	
2·95	2·95	2·95	3·50	3·50	3·50	1·24	1·47	7·59	9·03	161,504
7·55	7·55	7·55	8·95	8·95	8·95	3·17	3·76	19·40	23·10	
2·36	2·36	2·36	0·01	0·01	0·01	0·53	0·06	6·46	0·03	206,640
6·04	6·04	6·04	0·03	0·03	0·03	1·35	0·16	16·50	0·09	
2·84	2·84	2·84	3·38	3·38	3·38	0·59	0·70	7·93	9·44	196,784
7·27	7·27	7·27	8·66	8·66	8·66	1·51	1·79	20·30	24·20	
1·33	2·16	1·33	1·16	1·56	1·16	0·63	0·21	4·74	0·70	230,608
3·41	5·53	3·41	2·97	4·00	2·97	1·61	0·54	12·13	1·79	
2·10	3·50	2·10	1·88	2·46	1·90	0·48	0·05	7·10	1·30	162,624
5·38	8·96	5·38	4·82	6·30	4·87	1·23	0·13	18·20	3·32	
2·03	2·95	1·99	1·77	1·63	1·79	0·64	0·06	6·45	2·00	194,880
5·20	7·55	5·10	4·54	4·17	4·58	1·64	0·15	16·50	5·12	
1·50	1·79	1·00	2·80	2·03	0·77	Not allowed		0·71	1·54	199,360
3·84	4·58	2·56	7·17	5·20	1·98	for		1·83	3·94	
3·74	3·74	3·74	4·49	4·49	4·49	do.		11·23	13·48	168,000
9·54	9·54	9·54	11·5	11·5	11·5			28·60	34·50	
3·35	3·35	3·35	3·93	3·93	3·93	do.		10·05	11·79	175,728
8·56	8·56	8·56	10·10	10·10	10·10			25·68	31·50	
Nil hammer-blow at all speeds.								—	—	207,200
L 1·04	2·10	1·04	0·89	1·76	0·89	—	0·58	4·17	4·10	187,040
R 0·43	0·86	0·43						1·71		
L 2·66	5·39	2·66	2·28	4·50	2·28	—	1·48	10·70	10·5	
R 1·10	2·20	1·10						4·40		
2·23	2·26	2·23	3·08	3·08	3·08	—	1·19	6·72	7·20	181,328
5·71	5·80	5·71	7·90	7·90	7·90	—	3·04	17·20	18·42	
1·44	—	1·44	0·10	—	0·10	—	0·06	2·87	0·27	150,304
3·68	—	3·68	0·27	—	0·27	—	0·15	7·35	0·69	

† Some of these engines have 85 per cent.

Western Railway has, on certain two-cylinder suburban tank engines, increased the proportion to 85 per cent. as a contribution to the avoidance of fore-and-aft oscillations which are unpleasant to passengers. The Southern Railway, on the other hand, has adopted values of 40 and 30 per cent., and on its most modern design, with three-cylinders, has elimi-

Fig. 2.



TYPICAL HAMMER-BLOW DIAGRAMS: GREAT WESTERN AND LONDON AND NORTH EASTERN RAILWAYS.

nated reciprocating balance altogether. Continuous efforts have been made to reduce the weights of the parts themselves by improved design, and by the use of high-tensile alloy steels, and the low weights attained on the London and North Eastern engines are noteworthy.

Division of reciprocating balance among the coupled wheels.—On two-cylinder engines the usual practice for many years has been to divide the weight required to balance the reciprocating parts equally among the coupled wheels, with the object of lessening the hammer-blow per wheel and per axle.

Three-cylinder engines having cranks at 120 degrees are dealt with in two different ways.

The London, Midland and Scottish Railway balances two-thirds of both inside and outside reciprocating weights, the whole being equally divided between the coupled wheels; thus there is in each wheel a component for inside cylinder, outside cylinder, and cross couple. The resultant balance weight and hammer-blow effect is in nearly opposite directions in the left-hand and right-hand wheels, as shown in *Figs. 1*; so that whilst there is an appreciable blow on each wheel and each rail, there is only a negligible amount on each axle and on the engine as a whole. Such an engine, although exerting a smaller hammer-blow per rail than a two-cylinder engine by reason of its lighter reciprocating parts per cylinder, is nevertheless inferior to a four-cylinder, and it will be noticed from Table I that the London, Midland and Scottish three-cylinder, 4–6–0 engine of class 5X exerts as great a hammer-blow per wheel and per rail at 5 revolutions per second as the larger and more powerful four-cylinder "Coronation" engine does at 8 revolutions per second.

The method adopted by the London and North Eastern Railway is to distribute the outside balance among all the coupled wheels in the usual way, but to balance the inside reciprocating parts in the main driving-wheels alone. This has two results. Firstly, because there is no component for the inside cylinder in the leading and trailing wheels, the left-hand and right-hand wheel-blows, instead of being almost exactly opposite, as in the London, Midland and Scottish engines, are now approximately 120 degrees apart, so that instead of an inappreciable axle hammer-blow, there is a very definite variation in load. Secondly, since the whole of the inside balance is in the driving-wheels—and this is, of course, much heavier than the one-third of the outside weights balanced therein—the inside balance weight becomes master of the situation, and the axle hammer-blow on the driving-wheel occurs in the opposite direction to that on the leading and trailing wheels, as shown in *Figs. 2*. There is, in consequence, a considerable reduction in the whole engine blow. It is for the bridge engineer to say which is the better of these two methods, if like be compared with like.

In the case of four-cylinder engines, driving into a single axle and having adjacent inside and outside cranks at 180 degrees, and left- and

right-hand pairs at 90 degrees to each other, the reciprocating parts on each side balance one another almost completely, but balance weights are introduced to deal with the cross couple, the required weight being usually equally divided among the coupled wheels. The hammer-blow per axle and per engine is thus nil, but there is a small blow per wheel and per rail. When the drive is divided, the inside cylinders driving the leading axle, and the outside cylinders the intermediate axle, the same remarks hold good, provided it is assumed that the side rods adequately keep the two reciprocating systems in phase. Such an assumption is made in London, Midland and Scottish design, the small amount of play which develops in the side rod bushes having a negligible effect.

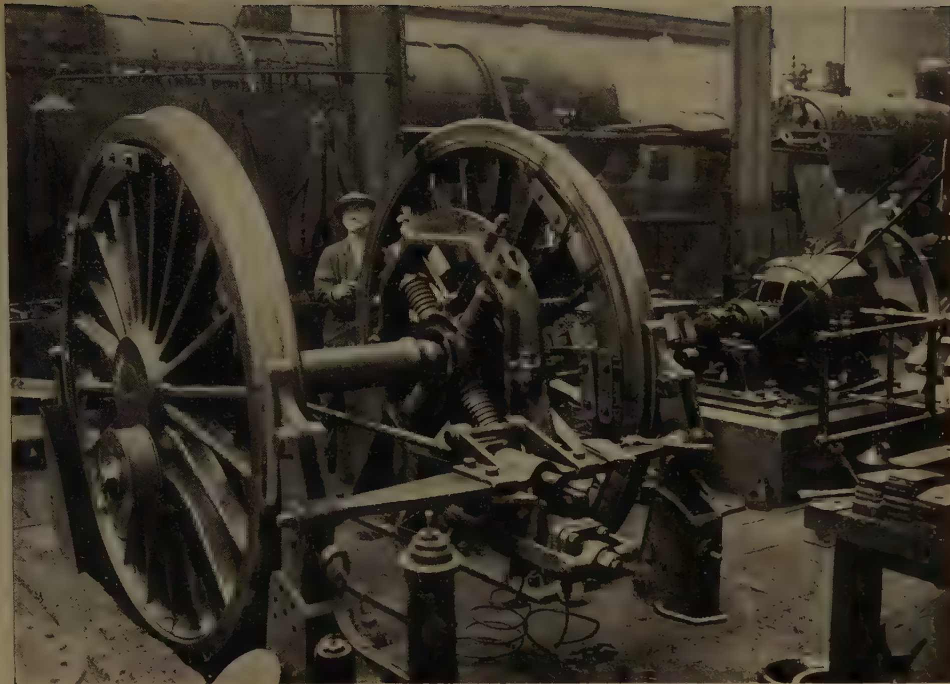
The Great Western Railway, unlike the London, Midland and Scottish Railway, divides the inside balance between leading and trailing wheels only, and the outside balance between intermediate and trailing wheels. This is done with the object of reducing stresses in side rods and frames, but as will be seen from Table I, it results in a definite blow per axle, as against no blow by the London, Midland and Scottish method. *Figs. 2* show how the maximum hammer-blows per wheel occur in opposite directions on adjacent wheels so that the total blow per rail is small.

The various methods of distributing the reciprocating balance among the coupled wheels may give certain small advantages in one direction, usually at the expense of small disadvantages in another; but for given reciprocating weights and a given percentage of masses balanced there is no evidence that either the gains or losses are of a decisive nature.

Slidebar hammer-blow.—Where this is taken into account it is not strictly a hammer-blow in the same sense as that due to the revolving weights, but is rather a variation in pressure acting on the frame of the engine through the slidebars. This is due to the fact that the centres of percussion, of gravity, and of the big end are not coincident, and it usually acts in the opposite direction to the hammer-blow in the wheels.

Wheel-balancing machine.—After theory has determined the magnitude of the balance weight and its angular position in relation to the crank, it is necessary to make a practical check on the wheels themselves, because inequalities in density of metal and thickness of sections can cause material divergence from what is intended. A simple form of static balancing can afford a rough and ready check; but to cover the effect of the cross-couple at speed there is no substitute for dynamic balancing, that is, revolving the wheels at the highest required speed, and adding or subtracting weight until the wheels run true. *Fig. 3* shows a form of machine for this purpose, on which it is desirable that every pair of coupled wheels should be checked when new, or after any alteration in design. Originally introduced at Swindon, such machines have since been installed at Crewe, Derby, Doncaster, Darlington, and Eastleigh, and are a safeguard against engines getting into traffic with other than the intended amount of balance.

Fig. 3.



WHEEL-BALANCING MACHINE.

Fig. 4.

COUPLED WHEEL LIFTING AT HIGH SPEED OF REVOLUTION.

Fig. 5.

KINK IN TRACK AFTER SLIPPING TESTS.

Fig. 6.

DAMAGED RAIL AFTER REMOVAL.

Speed.—The outstanding change since 1928 has been in speed. The Bridge Stress Committee's recommendations were based on a rotational speed of 5 revolutions per second, although many examples were worked out in the report at 6 revolutions per second, which was considered to be the highest speed attained in service. Before the war maximum operating speeds had risen to 90 miles per hour, whilst on special tests speeds of up to 125 miles per hour had been attained. Moreover, high speeds have not, as formerly, been confined to large-wheel engines, thus keeping the speed of rotation down. Modern free-running valve gears allow even mixed-traffic engines with 6-foot wheels to attain and exceed 90 miles per hour in ordinary service. A rotating speed of 8 revolutions per second, which represents 103 miles per hour with a 6-foot wheel and 115 miles per hour with a 6-foot 9-inch wheel, is, therefore, a definite possibility, and will have to be allowed for in future. Table I shows the magnitude of hammer-blows on existing engines at such a speed; and the allowable values so far allowed by the bridge engineers will need to be reviewed sooner or later. If, for example, it is going to be required in future that engines shall develop at 8 revolutions per second no greater hammer-blows than they do now at 5 revolutions per second, a reduction in the amount of reciprocating balance which can be admitted will be called for, and the whole subject of the effect of the unbalanced forces on the engine will assume a new range of importance.

Capacity for high speed has also produced, in the last few years, a new phenomenon not previously observed, namely actual bouncing of the coupled wheels on the track. This first came to light in the United States in about 1937, when running speeds were increased with existing locomotives higher than they had ever been before. It must be explained that American practice has differed from British in paying less attention to cross-balancing of rotating parts; and although it has been customary to balance only low percentages of reciprocating parts, this has been offset by the usually much heavier weight of those parts. Resultant hammer-blows have thus been excessive in some cases.

In spite of occasional outbreaks of broken and bent rails, the effect of this phenomenon passed for many years comparatively unnoticed, the great strength of the track and bridges absorbing the vertical forces. With higher speeds, however, and particularly where slipping of the wheels has occurred, the wheels have been found actually to leave the track by an appreciable amount, and to bounce up and down, delivering heavy blows to the rails. Full descriptions of experimental observations and the steps taken to avoid the trouble have been published [1].

In Great Britain no authentic observation had been made of similar occurrences, but from time to time rather mysterious cases of bent rails occurred which evidence seemed to connect with slipping of locomotive

---

[1] T. V. Buckwalter and O. J. Horger, *Railway Mechanical Engineer*, vol. 113, pp. 85, 132, 136; April, 1939.

coupled wheels, and an investigation was put in hand as described below.

Coupled wheel lifting.—The tests were carried out by the Research Department of the London, Midland and Scottish Railway. Two two-cylinder 4–6–0 mixed traffic engines of class 5 were selected, having 66·6 per cent. and 50 per cent. balance respectively, whilst a third engine was specially altered to have only 30 per cent. Rail-heads on a specially selected length of track were greased to promote slipping and the equivalent slipping-speeds were measured accurately by means of a slow-motion cine-camera, taking sixty-four frames per second, the camera also serving to provide a photographic record of the movements of the wheel on the rail. Slipping-speeds ranging up to 110 miles per hour were obtained, the engines moving along the rails at speeds ranging from 10 to 18 miles per hour. The results obtained are set out in Table II, whilst *Fig. 4* shows the wheel actually leaving the rail and *Figs. 7* set out in diagrammatic form representative amplitudes of displacement and frequency. As may be imagined, the bouncing of the wheels caused severe damage to the track, the rail being bent by the succession of wheel impacts in such a way that the ends tended to lift above the level of the middle portion. The ballast was damaged so that permanent settling of the track occurred. In all the tests the amplitude of the vertical oscillation of the driving wheels was greater than that of the leading or trailing wheels, although the hammer-blows are the same.

TABLE II.—RESULTS OF WHEEL-LIFTING TESTS.

Engine No.	5043		5464		5406	
Percentage of reciprocating parts balanced	66·6		50		30	
Slipping-speed: m.p.h.	103		104		99	
Maximum lift of driving-wheel: inches	2·4		0·4		No appreciable lift	
Engine oscillations	Nothing abnormal		Moderate		Excessive	
Hammer-blow	5 r.p.s.	103 m.p.h. = 8 r.p.s.	5 r.p.s.	104 m.p.h. = 8 r.p.s.	5 r.p.s.	99 m.p.h.= 7·7 r.p.s.
Per wheel: leading, driving, and trailing: tons	3·84	9·82	2·95	7·55	1·76	4·18
Per axle: leading, driving, and trailing: tons	4·28	11·00	3·50	8·95	2·10	4·98
Total engine blow per rail: tons	10·36	26·60	7·59	19·40	4·04	9·60
Whole engine blow: tons	11·52	29·55	9·03	23·10	4·83	11·48

This appears to be due to the position of the driving-wheels near the

Fig. 7.

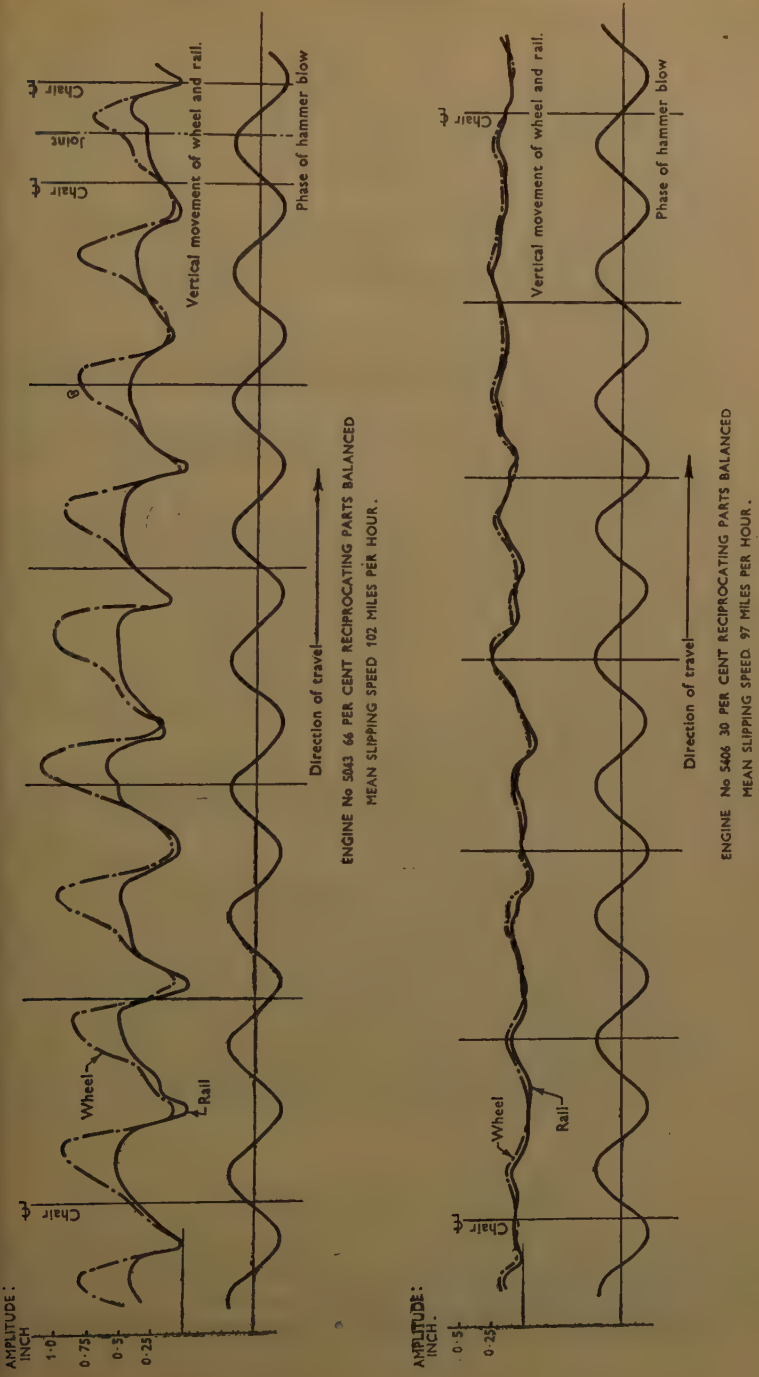


Diagram to Illustrate Wheel Bouncing.

centre of the deflected length of the track. *Figs. 5* and *6* show the values of the damage to the track. The following are the deductions which were made from the experiments :—

(i) The bouncing of the wheels is of the nature of a forced vibration, resulting from the unbalanced forces, and is not one of resonance between engine and track.

(ii) In these circumstances the wheels lift at rather lower speeds than indicated by theory, in which upward centrifugal action of the balance weight and static load of the wheel downwards on the track are alone considered.

(iii) Bouncing and track damage become less as the hammer-blow diminishes: no appreciable wheel-lift occurred with 30 per cent. balance.

(iv) The limiting factor in reduction in hammer-blow, so far as these tests are concerned, is the fact that undue oscillations were observed on the engine with 30 per cent. balance.

(v) The condition of the track has little effect on the incidence or extent of wheel-lift, which depends primarily on the hammer-blow.

After these tests the proportion of balance on this class of engine was standardized at 50 per cent., instead of 66·6 per cent.

Summary of existing practice.—The foregoing sections of the Paper indicate the steps already taken towards reducing hammer-blow, and set out some good reasons why it should be reduced to as low an amount as possible, even if it cannot be eliminated.

That this has not been done already is due to the fact, clearly demonstrated by theory, that the engine itself must be correspondingly subject to horizontal disturbing forces which—especially in the case of two-cylinder engines—may attain a large magnitude. The effect of these horizontal forces on the locomotive is, however, unlike the hammer-blow effect, very ill defined. Neither recorded theory nor experiment has so far analysed clearly the resulting oscillations, showing, on the one hand, how they vary in relation to engine weight, length, and weight of unbalanced reciprocating parts, and on the other hand, what proportion they form of the total locomotive oscillations from all causes. Such being the case, the tendency has been to " play for safety " and in most cases to continue to balance a substantial portion of the reciprocating parts.

Effect on the Locomotive.

A locomotive running on the track is subject to some ten separate kinds of disturbance. Two of these are relevant to the subject of this Paper: (1) a lateral oscillation or nosing motion, and (2) a fore-and-aft or shuttling motion, both due to the effect of unbalanced reciprocating parts.

The remainder of the ten have been very comprehensively dealt with elsewhere.[1]

Effect of nosing couple.—The effect of the nosing couple is greatest in a two-cylinder engine, in which type its maximum value is given by the expression $\frac{W\omega^2 rd}{\sqrt{2}g}$, where W denotes the unbalanced reciprocating weight per cylinder, in pounds; ω denotes angular velocity, in radians per second; r denotes the crank radius, in feet; and d denotes the distance between cylinder centres, in feet. Thus the value of the couple increases as the square of the speed.

The action of this couple is resisted by the inertia of the engine, and an expression for the value, in inches, of the amplitude of the resulting oscillation can be worked out for a two-cylinder engine, as shown in Appendix I, p. 246, *post*, from the expression:—$A = \frac{Wdrm}{\sqrt{2}gI}$, where A denotes the semi-amplitude, in inches, of oscillation at the bogie centre; m denotes the distance of the bogie-centre from the centre of gravity of the engine, in inches; and I denotes the moment of inertia of the engine about a vertical axis through its centre of gravity. It is of interest to notice that the amplitude is independent of speed of rotation. In simple terms this means that whilst the disturbing force increases as the square of the speed, so also does the resistance of the mass of the engine to displacement, the effect of speed thus being nullified.

If values are substituted for modern engines it will be found that this semi-amplitude is very small. On the London, Midland and Scottish Railway two-cylinder mixed-traffic engine, for example, it is only 0·03 inch with 50 per cent. of the reciprocating weights balanced, 0·04 inch with 30 per cent., and 0·06-inch with zero reciprocating balance. For multi-cylinder engines the values are smaller still, and in all cases they are less than the normal side clearance in the axleboxes and in the bogie centre-pin. In such circumstances, these oscillations will not act upon the bogie side control springs, and no question of resonance is likely to occur.

A wider view can be obtained by assuming the moment of inertia of the engine to be that of a slab of metal of weight W_L equal to that of the engine, of breadth B equal to 5 feet, and of length L equal to that of the engine from the leading bogie wheel-centre to the rear end of the firebox. Inserting the appropriate expression for the moment of inertia, the formula becomes

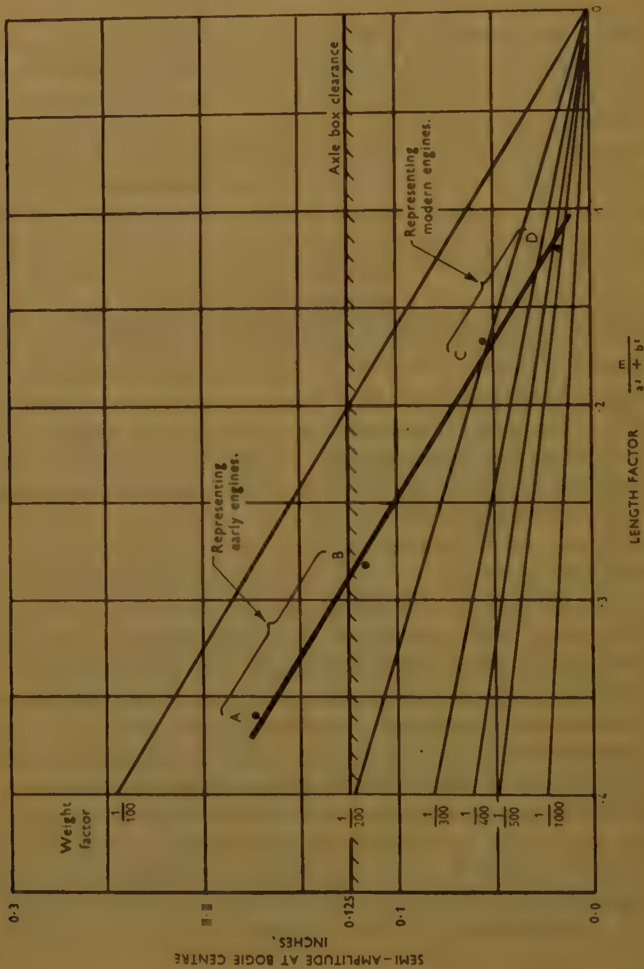
$$A = \frac{12dr}{\sqrt{2}} \times \frac{W}{W_L} \times \frac{m}{(L^2 + B^2)}.$$

Fig. 8 shows values of A plotted against $\frac{W}{W_L}$ and $\frac{m}{L^2 + B^2}$. The former

[1] Pacific Locomotive Committee Report (Government of India Press, New Delhi), 1939.

fraction is the ratio of unbalanced reciprocating weight to engine-weight, which may vary from $\frac{1}{100}$ to $\frac{1}{1,000}$; whereas the latter depends upon the length of the engine, and may vary from 0·4 to 0·1, the first figures

Fig. 8.



NOSING AMPLITUDE AT BOGIE CENTRE PIN.

in each case being representative of a small early type of locomotive an the latter of a heavy, long, modern locomotive.

A horizontal line has been drawn across the graph at a semi-amplitud of 0·125-inch, which is the normal total side clearance of the axleboxes Oscillations above this value can be expected to affect the riding of th

engine on the track. A heavy line has also been drawn on the graph connecting values for the following engine proportions :—

Type.	Length : feet.	Weight : tons.	Weight of unbalanced reciprocating parts : lb.
A.	15	20	350
B.	20	40	500
C.	35	70	800
D.	50	200	1,000

It will be seen that disturbances greater than the amount of the axlebox clearances are likely to occur only with locomotive proportions obtaining in the early days of railways, and not with those obtaining on any modern engines, even with nil reciprocating balance.

Confirmation of this is to be found in the work of the Indian Pacific Locomotive Committee, and their report clearly ruled out oscillations from the cause discussed above as having any practical influence in the nosing and hunting of locomotives on the track, which, owing to quite other causes, was able to build up in certain circumstances to dangerous values.

In so far as lateral nosing movement alone is concerned, therefore, there appears to be no necessity to introduce reciprocating balance on any modern engines ; but the situation is otherwise when the longitudinal disturbing forces are studied.

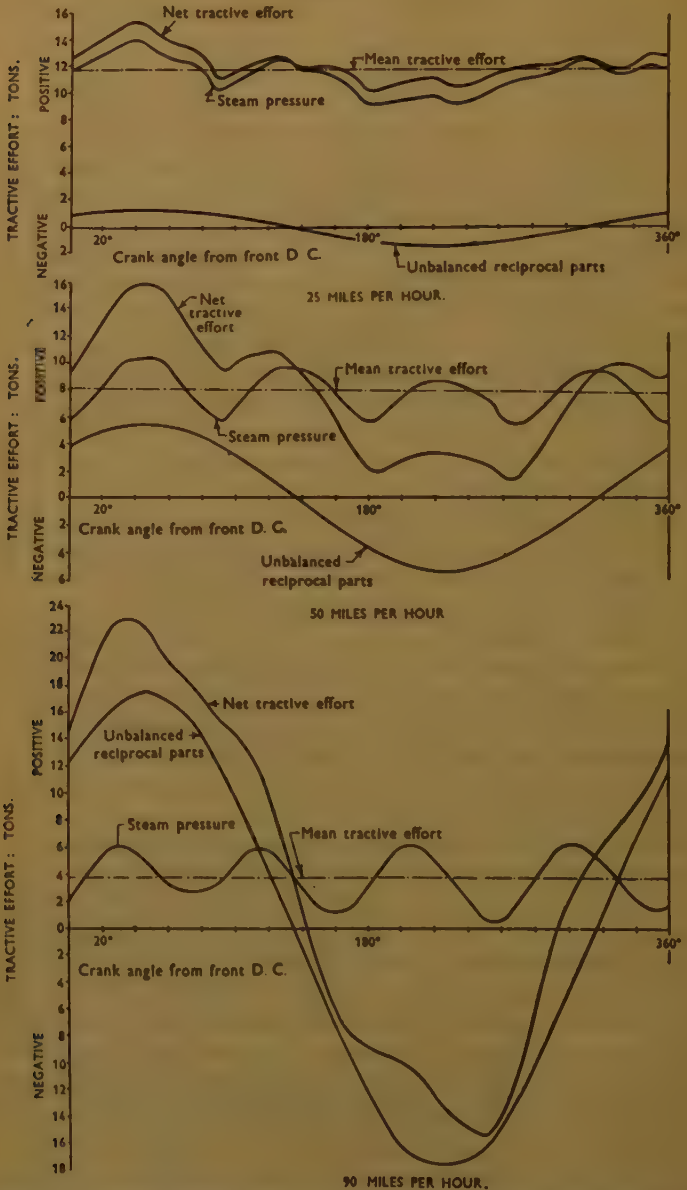
2. *Effect of longitudinal force.*—The forces applied through the axleboxes and frames of a locomotive, appearing at the drawhook as available tractive effort, are made up of two distinct components. Firstly, there is the effect of the steam-pressure in the cylinders, the tractive effort exerted thereby varying above and below a mean value because of the change in steam-pressure during the travel of piston along its stroke, and the effective length of the crank on which the steam-pressure acts. Secondly the longitudinal force due to the effect of the unbalanced reciprocating parts attains a positive and a negative value for each cylinder once during each revolution. The resultant effect depends upon the number of cylinders and the crank angles between them.

On three-cylinder and four-cylinder engines of conventional type, the primary horizontal forces due to the reciprocating parts are in balance among themselves, given equal connecting-rod weights ; and no variation in tractive effort at the drawbar arises from this cause. Theoretically, no additional balancing of these parts is necessary, therefore, on such engines. The following investigation is consequently concerned with two-cylinder engines. On these engines the forces in question do not balance, and the resultant takes the form of a fluctuating force tending to accelerate and decelerate the locomotive along its longitudinal axis, with a frequency of once per revolution. The maximum value of this force for such an engine is $\pm\sqrt{2}\frac{W\omega^2 r}{g}$.

The manner in which the force due to steam-pressure and that due

to unbalanced parts vary with speed is shown in *Fig. 9*, which refers to a large two-cylinder engine having 50 per cent. of its reciprocating parts

Fig. 9.



Curves of Tractive Effort for Two-Cylinder Engine at Various Speeds.

balanced. At low speeds the steam-pressure effect predominates, but as the speed increases the effect of the unbalanced parts increases, until at 90 miles per hour there is an alternating force which ought to cause the drawbar pull to fluctuate between $+$ 23 tons and $-$ 15 tons each revolution.

Although the conditions outlined above truly represent the forces acting on the locomotive, it is common knowledge that such large fluctuations are not felt on the footplate or in the train, nor are they recorded on the dynamometer-car chart. The explanation lies in the fact that the frequency of the disturbing force is many times greater than the natural frequency of the elastic system as a whole, comprising the mass of the locomotive and of the train, and the elastic characteristics of the drawbar springs.

A complete mathematical study allowing for the frequencies of the different drawbar springs throughout the length of the train and for the varying damping factors involved, would be very complex. It is possible, however, to work out a simplified expression to give the value of maximum variation in drawbar pull D_1 due to the effect of the unbalanced forces in relation to engine and train weights, by assuming a single spring between engine and train, of the kind usual in dynamometer cars. The derivation of the formula, which was jointly undertaken by the Chief Mechanical Engineer's and the Research Departments of the London, Midland and Scottish Railway, is set out in Appendix II, p. 247, *post*, and takes the form

$$D_1 = \pm \frac{\sqrt{2}Wr\omega^2}{W_L\sqrt{\left[\left(\frac{1}{W_L}+\frac{1}{W_T}\right)k-\omega^2\right]^2+\left(\frac{1}{W_L}+\frac{1}{W_T}\right)^2\omega^2 f^2}}$$

where W_T denotes the weight of the train, in tons; k denotes the stiffness of the drawbar spring, in tons per foot, that is, the modulus in tons per foot multiplied by g; and f the damping factor of the drawspring.

In *Fig. 10* are plotted the maximum variations in drawbar pull at 90 miles per hour for a variety of engine weights and for different weights of unbalanced reciprocating parts. The same train-weight has been assumed throughout; k has been taken as $36g$ tons per foot (spring stiffness 3 tons per inch), and f as $\frac{36g}{7}$. The interpretation of these results depends upon what value is selected as the permissible amount of variation in drawbar pull for good riding. From a scrutiny of dynamometer-car records a variation of $\pm 0{\cdot}2$ ton pull has been chosen equal to $\pm 0{\cdot}06$ inch, and a line is drawn across the graph at that value. It will readily be seen that there are many categories of two-cylinder locomotives in which some degree of reciprocating balance is necessary. For example, the London, Midland and Scottish 4–6–0 mixed traffic engine weighing 72 tons is shown to require $933 - 530 = 403$ lb. balanced if undue oscillations above $\pm 0{\cdot}2$ ton at the drawbar are to be avoided. This represents 43 per cent. of the

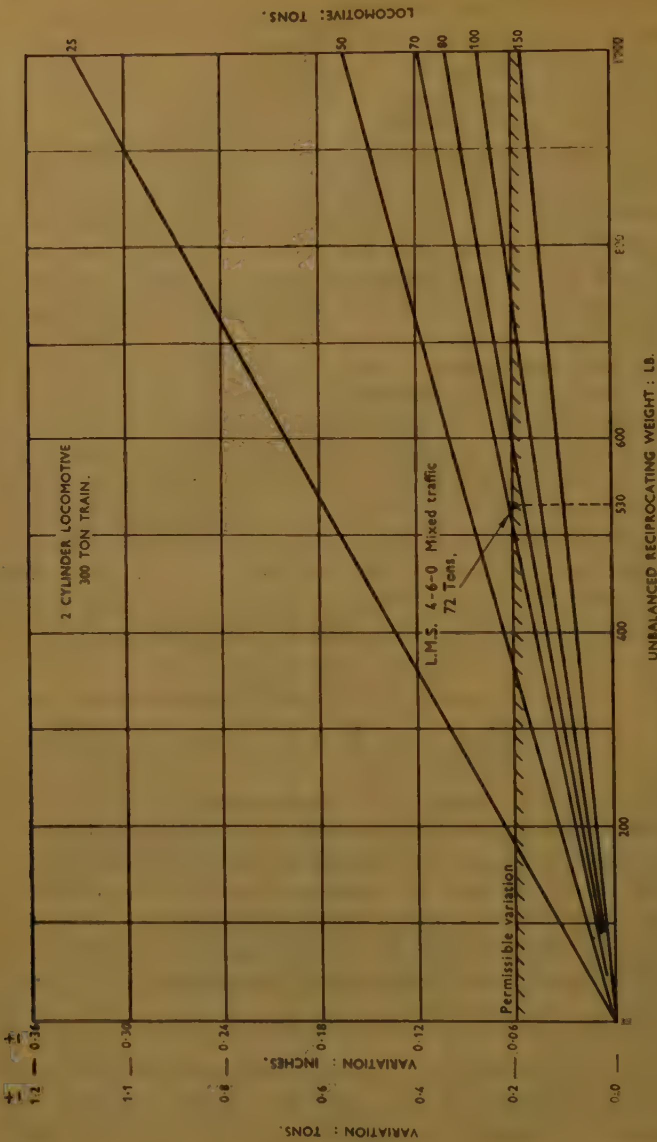


Fig. 10.

VARIATION IN DRAWBAR PULL AT 90 MILES PER HOUR.

reciprocating weights balanced. In actual fact, as already stated, the balance has been standardized at 50 per cent. on this class. Variations in the weight of the train within normal working limits can be shown to have a negligible effect.

At this point two questions require an answer.

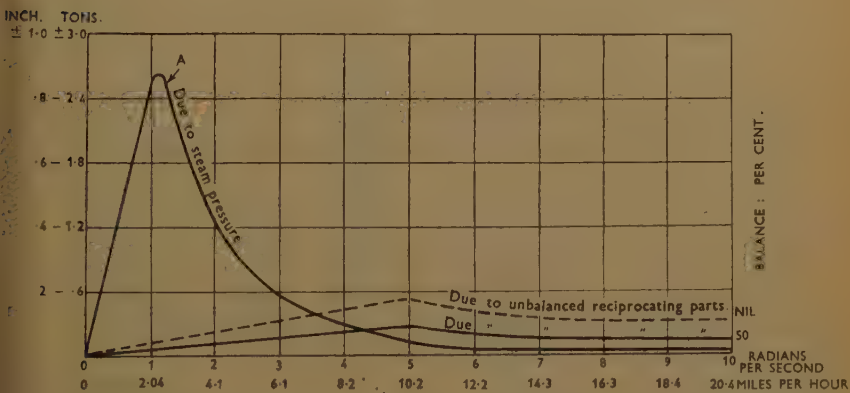
(1) To what extent do the horizontal disturbances due to steam-pressure variations in the cylinders augment the values given above ?

(2) Is a condition of resonance likely to arise in the locomotive and train, in which the oscillations might build themselves up to considerably greater values ?

With regard to question (1), the resulting oscillation (D_2) can be worked out in a similar manner, as indicated in Appendix III, p. 248, *post*, but since the frequency of the impulses is 4 times that of the other disturbance, the additional variation in drawbar pull is a very small quantity and can be neglected at any but very low speeds.

With regard to question (2), it is necessary to investigate separately the maximum values for the amplitudes D_1 and D_2, since the initiating forces vary differently with the angular velocity. This has been done in Appendix

Fig. 11.



Conditions of Resonance and Maximum Oscillations of Two-Cylinder 4–6–0 Engine, London, Midland and Scottish Railway.

IV, p. 250, *post*, and *Fig. 11* shows the values plotted for the London, Midland and Scottish 4–6–0 mixed traffic engine, from which it can be seen that—

(*a*) resonance is likely to occur only at very low speeds ;

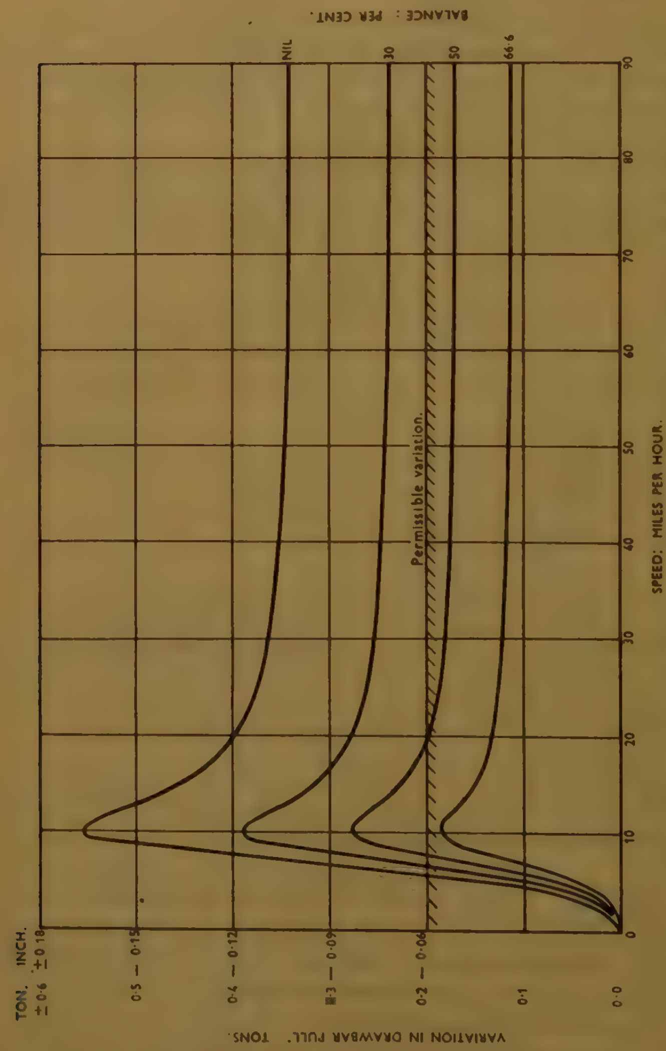
(*b*) from 0 to 6 miles per hour D_2 is the predominating factor, reaching a maximum value of 0·88 inch at 2·1 miles per hour ; beyond 10 miles per hour its effect is negligible ;

(*c*) D_1 attains a maximum value at 10 miles per hour, and then falls away to a practically constant value for speeds exceeding 15 miles per hour.

With other drawbar spring characteristics, the speed of resonance can, of course, vary considerably and a combination of the various factors is conceivable in which maximum values for the effects of steam and centri-

fugal forces coincide at the same running-speed. The result may be uncomfortable for the passengers and call for some alteration in the method of working the engine, or of the drawbar spring characteristics. Only in very

Fig. 12.



THEORETICAL VARIATION IN DRAWBAR PULL WITH SPEED: LONDON, MIDLAND AND SCOTTISH RAILWAY 4-6-0 MIXED TRAFFIC ENGINE CLASS 5.

rare cases should it be necessary to increase the proportion of the parts balanced.

Fig. 12 amplifies item (*c*) above, for the same engine with varying per-

centages of balance, and underlines the fact that the magnitude of the oscillation remains constant with increase in speed.

Verification of the Foregoing Theory.

It must be confessed that scientific experimental investigation into horizontal disturbances in a locomotive apart from those arising from its function as a vehicle on the track, has not yet been undertaken on British railways. Three methods—none of scientific exactitude—have been available for this purpose, namely, (1) riding on the footplate; (2) studying dynamometer records of drawbar pull; (3) examining cine-films of the engine in motion.

(1) The first method, whilst very imperfect, enables any marked departure from normal vibration to be distinguished. The following experiences by this method may be cited :—

(i) When a London, Midland and Scottish 4–4–0 engine weighing 55 tons was converted to have nil reciprocating balance, fore-and-aft vibrations were experienced sufficient to cause discomfort on the footplate, and bring the coal down off the tender. The engine was returned to normal 66·6 per cent. balance after 6 months.

(ii) A London, Midland and Scottish two-cylinder tank engine weighing 86 tons and having 677 lb. of reciprocating parts per cylinder, has been running for 8 years without any reciprocating balance. No adverse report has ever been made on its riding.

(iii) The Author, when travelling in India on the footplate of a 4–6–2 engine of 90 tons weight having the whole of its reciprocating parts, weighing 855 lb. per cylinder, unbalanced, experienced a definite fore-and-aft vibration at about 10 miles per hour, quite unlike any vibration encountered on other similar engines normally balanced. At higher speeds this effect died away.

These experiences, so far as they go, confirm the result given in *Figs. 10* and *11*.

(iv) The Southern Railway three-cylinder "School" class was originally built with only 30 per cent. balance. In May 1939 one of these engines was altered experimentally to nil balance. No difference in the riding of this engine has been reported. As a result of this experience, reciprocating balance has been omitted from the new three-cylinder "Merchant Navy" class.

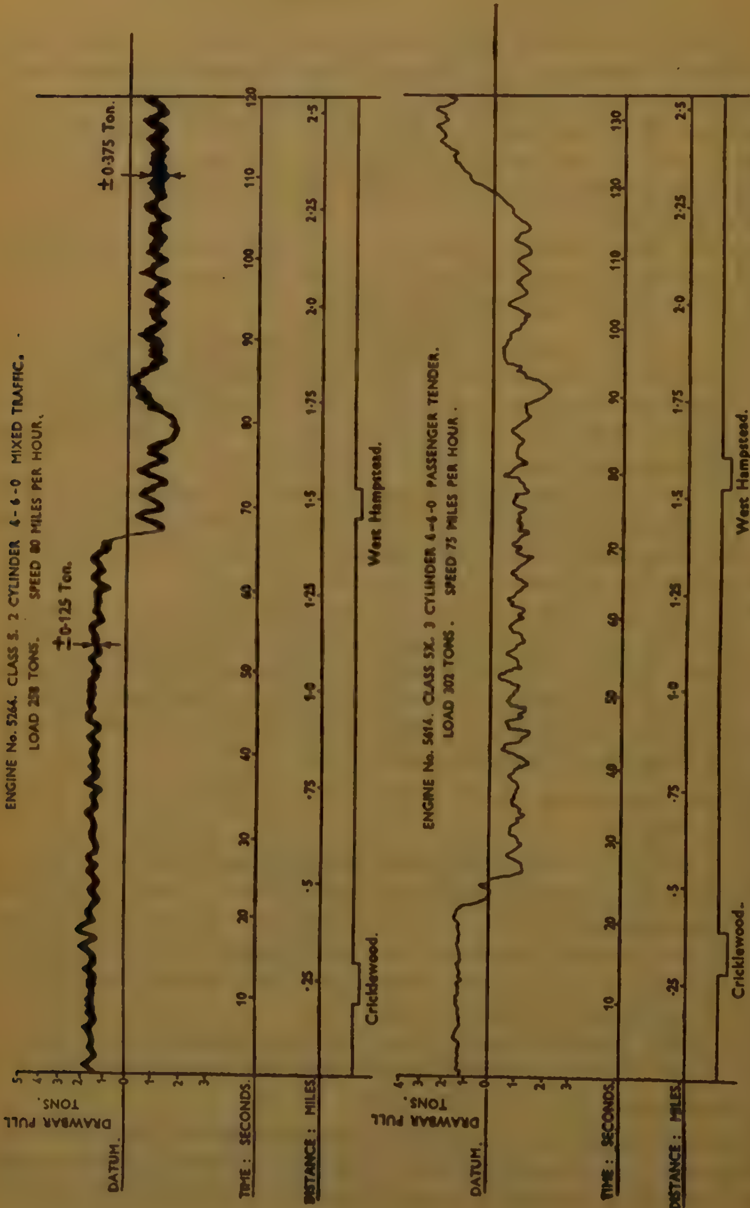
This tends to confirm what has been pointed out above from theoretical considerations, namely, that reciprocating balance is not required on three-cylinder engines.

(2) Judgement on the basis of dynamometer-car records is much more exact, but is also imperfect in that the amplitude of drawbar variations recorded thereon is also affected by other influences, such as the riding

qualities of the engine and tender, the condition of the track, and the incidence of brake applications. Examples are :—

(v) *Fig. 13* shows reproductions of two such records made at the

Fig. 13.

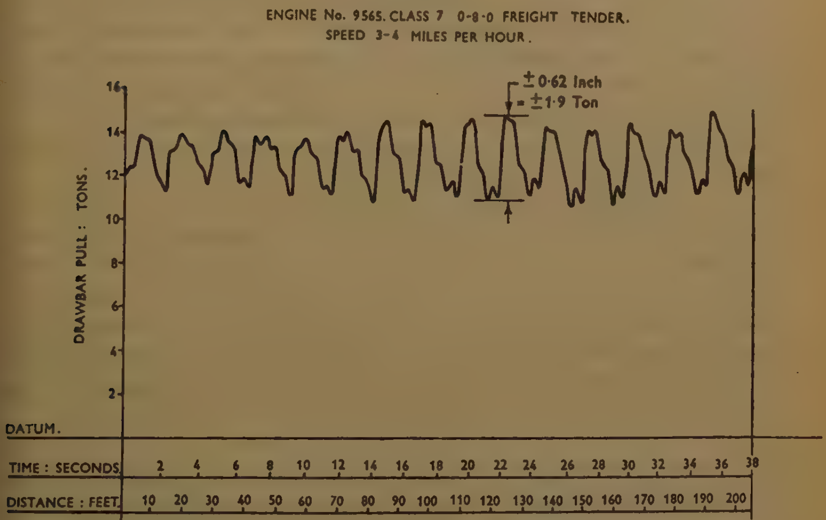


VARIATION IN DRAWBAR PULL AT HIGH SPEED, SHOWING EFFECT OF UNBALANCED RECIPROCATING PARTS.

same place and at approximately the same speed with a two-cylinder engine having 55 per cent. balance, and a three-cylinder engine with 66·6 per cent. balance but which, by reason of its 120-degree crank-setting, has nil horizontal "shuttling" disturbance.

It will be seen that the former engine shows a variation in drawbar pull averaging the order of magnitude indicated by theory; and any greater variation would undoubtedly be felt in the train and cause discomfort to passengers. The three-cylinder engine is free from rapid vibrations, but the irregularities visible in its drawbar line indicate the value of the other influences to which reference has been made.

Fig. 14.



VARIATION IN DRAWBAR PULL AT VERY SLOW SPEEDS DUE TO RESONANCE WITH DRAWBAR SPRING.

(vi) *Fig. 14* shows a record of an engine pulling hard at 3–4 miles per hour. The oscillations are entirely due to (*a*) variations in steam-pressure in the cylinder and (*b*) their resonance with the drawbar spring characteristics, and the oscillation corresponds with line A in *Fig. 11*.

(3) The remaining observation referred to is contained in the cinematograph film records made in the wheel-bouncing tests referred to on p. 230, *ante*. Here, oscillation of the engine is clearly seen to increase as the percentage-balance decreases on the London, Midland and Scottish 4–6–0 mixed traffic engine. In this special case, however, of an engine without train, slipping at high rotational (but low travelling) speed on a greased track, there was neither a clear nosing action about the engine's centre of

gravity nor a visible shuttling action; rather the engine was seen to oscillate sideways at the trailing end, appearing to pivot about the bogie-centre.

The observations outlined above emphasize the need for closer experimental investigation of this matter, both from the point of view of assessing separately the values of the various factors involved, and also with the aim of establishing some criterion defining the point beyond which the resulting oscillations are inadmissible from the point of view of comfort, wear and tear, and safety.

Mechanical effects.—Although unbalanced reciprocating parts can give rise to forces of considerable magnitude on axleboxes, guides, and frames, there is little evidence to show that the total elimination of this balance in a modern engine has any very serious effect upon these components. In the past engines have been underbalanced by mistake, and this fact has been brought to light, either by the Bridge Stress Committee's trials or by the introduction of dynamic balancing-machines; but there is no record that abnormal rate of wear indicated that anything was wrong.

Accurate information on this point is scarce and only the following two records are within the Author's knowledge:—

(*a*) The London, Midland and Scottish two-cylinder 2–6–4 tank engine No. 2408, already referred to, with zero balance, was carefully measured for wear in its coupled wheel bearings after 58,560 miles, in comparison with No. 2407, a sister engine having 66·6 per cent. balance, which had run the same mileage in the same district. The average measurements are set out in Table III; they are based on 50,000 miles running, which is the average distance at which axleboxes require attention on this class:—

TABLE III.—WEAR IN UNBALANCED AND BALANCED ENGINES.

The measurements are given in inches, equated to 50,000 miles' running.

Engine No.	2408	2407
Reciprocating weight per cylinder (unbalanced); lb.	677	226
Fore and aft wear in axleboxes (including wear in worn guides)	0·035	0·042
End play on journals	0·165	0·095
Roll in axleboxes	0·026	0·020
Wear in coupling rod bushes	0·015	0·013
End play in coupling rods	0·012	0·011
Wear in big-end bushes	0·012	0·011
End play in big ends	0·086	0·070

The wear is greater in the case of No. 2408, but is by no means excessive for the mileage run, and was not of a value which of itself would cause the engine to be stopped any earlier for repairs. This

engine has just been overhauled after 198,000 miles since last general repair, the axleboxes having been overhauled three times intermediately. No abnormal wear has been observed on any occasion.

(*b*) The Southern Railway "School" class three-cylinder engine, already referred to, with zero reciprocating balance, was reported to show no appreciable difference in wear from other engines of the class with 30 per cent. balance, when specially examined at general repair after 81,219 miles.

These two cases are special in that the first engine has a high total weight in relation to the reciprocating weights unbalanced, whilst the second, being a three-cylinder engine, does not demonstrate the worst effects of lack of balance. The question therefore remains open, so far as recorded experience in Great Britain goes, and the cases cited show only that when oscillations are small, increased wear is small.

Subject to later verification, it is reasonable to suppose that the rate of wear will vary with the amplitude of oscillation; and where that amplitude exceeds the permissible amount for tolerable riding, an undue degree of wear can be expected to develop, which in turn will intensify the effects of the unbalanced force.

Conclusions.

(1) The modern locomotive is capable of speeds of up to 8 revolutions per second, and the resulting hammer-blows with the usual percentages of reciprocating balance can attain much higher values than were visualized in the Bridge Stress Committee's report in 1928.

(2) The phenomenon of wheel-bouncing at high rotational speed was first observed in America in 1937, and tests have shown that it can occur in British practice in certain circumstances.

(3) Conclusions (1) and (2) suggest a reconsideration of locomotive design in the direction of reducing hammer-blow still further.

(4) As regards the effect on the locomotive, longitudinal and nosing oscillations depend upon the weight and length of the engine, the weight of reciprocating parts unbalanced, and the characteristics of the drawbar springs: they are independent of speed.

(5) Theory suggests that three-cylinder and four-cylinder engines which are already in a state of balance with regard to longitudinal forces do not require any portion of their reciprocating parts to be individually balanced to deal with the nosing couple, because of the small magnitude of the displacement. Three-cylinder engines with zero reciprocating balance are already running in Great Britain.

(6) In two-cylinder engines, theory—supported by a certain amount of practical evidence—indicates that some degree of reciprocating balance is still required if undue longitudinal oscillations are to be avoided. The percentage required will vary with the engine characteristics, and a method

has been suggested for arriving at the amount. Not less than 40 per cent appears to be required on the heavier type of British two-cylinder engine weighing from 65 to 75 tons.

(7) For the highest speeds, therefore, multi-cylinder engines are the most desirable, if they are of the reciprocating type. If it is thought necessary to balance a percentage of the reciprocating parts, the four-cylinder is preferable to the three-cylinder type from the point of view of hammer-blow. If this balance is eliminated, there appears to be little to choose between the two types.

(8) The final criterion as to what percentage of balancing is necessary is the magnitude of the oscillations which can be admitted on the engine having regard to riding comfort for the engine crew and passengers, wear and tear, maintenance costs, and safety.

(9) Practical experience so far recorded tends to support the theoretical conclusions. It is, however, very scanty, and when normal conditions return, scientific investigation will be required, not only to establish the precise effects of the unbalanced parts on the locomotive, but also to define the limiting value of the disturbances which can be admitted. More experimental verification is needed as a prelude to any large-scale reduction in hammer-blow.

Acknowledgements.

The thanks of the Author are due to Mr. W. A. Stanier, President I.Mech.E. for permission to publish information concerning the London, Midland and Scottish Railway, and to Mr. T. M. Herbert, M.I.Mech.E., for data on the wheel-lifting tests carried out by that Company. He also wishes to acknowledge information received from Mr. F. W. Hawksworth, M.I.Mech.E, Mr. E. Thompson, M.I.Mech.E., and Mr. O. V. S. Bulleid, M.I.Mech.E. concerning balancing practice on the Great Western, the London and North Eastern, and the Southern Railways, respectively.

The Paper is accompanied by ten sheets of diagrams and four photographs, from which the Figures in the text have been prepared, and by four Appendixes.

APPENDIX I.

General Notation.

A denotes Semi-amplitude of nosing oscillation at bogie centre : inches.

B ,, Width of engine : feet.

D_1 ,, Variation in drawbar pull due to unbalanced reciprocating weights : inches or tons.

D_2 ,, Variation in drawbar pull due to steam-pressure : inches or tons.

I ,, Moment of inertia of engine : Tons per square foot.

K denotes Stiffness of drawbar spring, in tons per foot, that is, modulus, in tons per foot times g.
L „ Length of engine: feet.
M_L „ Mass of engine.
M_T „ Mass of train.
W „ Weight of unbalanced reciprocating parts: lb. or tons.
W_L „ Weight of engine: tons.
W_T „ Weight of train: tons.
a „ Distance from centre-line of one cylinder to centre-line of engine.
d „ Distance between cylinder-centres.
f „ Damping factor of drawspring.
g = 32·2 feet per second per second.
m denotes Distance of bogie centre from centre of gravity of engine: inches.
n „ Frequency of variation of disturbing force.
r „ Crank radius: feet.
ω „ Angular velocity: radians per second.
v „ Speed of rotation: revolutions per second.
θ „ Crank angle.

APPENDIX II.

Calculation of Amplitude of Nosing Oscillation.

Unbalanced force per cylinder $= \dfrac{W\omega^2 r}{g}\cos\theta.$

Nosing moment due to one cylinder $= \dfrac{W\omega^2 ra}{g}\cos\theta$

For engine with two cylinders, and cranks at 90 degrees;

Couple due to both cylinders $= \dfrac{W\omega^2 ra}{g}(\cos\theta + \sin\theta)$

Maximum value of couple causing nosing $= \sqrt{2}\dfrac{W\omega^2 ra}{g}$ . . . . (1)

In terms of actual weights and revolutions per second, this maximum value for a two-cylinder engine becomes 0·85 Wv^2rd, where $d = 2a$.

For a three-cylinder engine with cranks at 120 degrees this value becomes 2·12Wv^2rd, where d denotes the distance between inside and outside cylinders.

For a four-cylinder engine with cranks at 180 degrees the value is 1·73Wv^2rd, where d denotes distance between centre-lines of a pair of cranks at 180 degrees.

The constants 0·85, 2·12, and 1·73 in these expressions include factors for the different definitions of d to suit the cylinder arrangement.

If values are substituted, comparing like with like as regards cylinder-power, it will be found that the outside two-cylinder arrangement gives the highest value of nosing couple, and the derivation of the amplitude of nosing oscillation which follows is, therefore, worked out for this type of engine.

To find an expression for this amplitude about a vertical axis through the centre of gravity of the engine, consider a rigid body oscillating with simple harmonic motion about an axis 0 with angular amplitude 2ϕ.

Let it be supposed that a particle P of weight dW_L is at a distance S from 0: then if there be n complete oscillations per second, the periodic time $= \dfrac{1}{n}$;

and maximum force on particle P $= \dfrac{dW_L \, . \, S\phi\omega^2}{g}$;

maximum moment of P about 0 $= \dfrac{dW_L S^2 \phi\omega^2}{g}$;

moment of the whole body about 0 $= \phi\omega^2 \Sigma S^2 d\dfrac{W_L}{g}$

But $\Sigma S^2 d\dfrac{W_L}{g} = I =$ moment of inertia of the body about 0.

Therefore maximum moment of the whole body

$$= \phi\omega^2 I \qquad \qquad (2)$$

To find the value of the semi-amplitude of oscillation, expressions (1) and (2) given above are equated:

Thus $$\frac{\sqrt{2}W\omega^2 ra}{g} = \phi\omega^2 I;$$

whence $$\phi = \frac{\sqrt{2}W\omega^2 ra}{g} \times \frac{1}{\omega^2 I}$$
$$= \frac{\sqrt{2}Wra}{gI} = \frac{Wdr}{\sqrt{2}gI}$$

The linear movement at the bogie-centre, distant m inches from the centre of gravity of the engine is obtained by equating the semi-amplitude A, in inches to $m\phi$:

Then $$m\phi = \frac{Wdrm}{\sqrt{2}gI} \qquad \qquad (3)$$

APPENDIX III.

Amplitude of Longitudinal Oscillation D_1: Two-Cylinder Locomotive and Train.

Let R_1 denote resistance to motion of mass M_L of engine;
R_2 „ „ „ „ M_T of train;
T „ tension or compression in drawbar spring;
x_1 „ distance of engine end of drawbar spring from a given ordinate;
x_2 „ distance of train end of drawbar spring from the same ordinate;
F „ applied force.
l „ natural length of drawbar spring.

The equations of motion are as follows:—

For M_L, $$\frac{M_L d^2x_1}{dt^2} = F - R_1 - T - f\left(\frac{dx_1}{dt} - \frac{dx_2}{dt}\right)$$

For M_T, $$\frac{M_T d^2x_2}{dt^2} = T - R_2 - f\left(\frac{dx_2}{dt} - \frac{dx_1}{dt}\right)$$

Stretched length of drawbar spring $= x_1 - x_2$.

Extension U of spring $= x_1 - x_2 - L$

Tension or compression T in spring $= KU$

The relative acceleration of the two masses is given by:—

$$\frac{d^2x_1}{dt^2} - \frac{d^2x_2}{dt^2} = \frac{F}{M_L} - \left(\frac{R_1}{M_L} - \frac{R_2}{M_T}\right) - \left(\frac{1}{M_L} + \frac{1}{M_T}\right)T.$$
$$- \left(\frac{1}{M_L} + \frac{1}{M_T}\right)f\left(\frac{dx_1}{dt} - \frac{dx_2}{dt}\right).$$

For simplicity, it may be assumed that $\dfrac{R_1}{M_L} = \dfrac{R_2}{M_T}$,

since neither has a periodic value. Thus the second term vanishes.

Then, as $T = KU$, it will be found that if $\left(\frac{1}{M_L} + \frac{1}{M_T}\right)f = f_1$;

and if $\left(\frac{1}{M_L} + \frac{1}{M_T}\right)K = K_1$;

the equation becomes

$$\frac{d^2U}{dt^2} = \frac{F}{M_L} - K_1U - f_1\frac{dU}{dt} \quad \ldots \ldots \ldots \quad (4)$$

This is the most general equation, and the form of its solution depends upon the form of F, the applied force.

This force F is the resultant of two periodic components, one due to the steam-pressure in the cylinders and the other to the forces set up by the unbalanced reciprocating masses.

Since ω is the angular velocity of the coupled wheels, the general expression for F is :—

$$F = \Sigma_n F_n \cos (n\omega t + an),$$

where n takes integral values and a is a constant introduced to account for differences of phase between the forces.

Thus equation (4) becomes—

$$\frac{d^2U}{dt^2} + f_1\frac{du}{dt} + K_1U = \frac{1}{M_L}\Sigma_n F_n \cos (n\omega t + an)$$

The solution is :—

$$U = e^{-\frac{1}{2}f_1t}[Ae^{(\sqrt{\frac{1}{4}f_1^2 - K_1})t} + Be^{(-\sqrt{\frac{1}{4}f_1^2 - K_1})t}]$$

$$+ \Sigma n \frac{\frac{F_n}{M_L}}{\sqrt{(K_1 - n\omega)^2 + n^2\omega^2 f_1^2}} \cos (n\omega t + an - \phi_n)$$

Where A and B are constants and $\tan \phi_n = \frac{n\omega f_1}{K_1 - n^2\omega^2}$

It will be seen that the first part of the solution is independent of ω and, therefore, of the applied forces. It represents the natural oscillations of the system which, under the three cases to be considered, namely $f_1^2 > 4K$, $f_1^2 = 4K$, and $f_1^2 < 4K$, can be shown to decrease rapidly to zero. In all three cases, therefore, the first part of the solution represents motion which persists for only a limited time, and which, therefore, need not be considered.

The second part of the solution represents the forced oscillations produced by the force F. Each component F_n produces oscillations of the same periodicity as itself of the form

$$U_n = \frac{\frac{F_n}{M_L}}{\sqrt{(K_1 - n^2\omega^2)^2 + n^2\omega^2 f_1^2}} \cos (n\omega t + an - \phi_n)$$

and of amplitude

$$D_n = \frac{\frac{F_n}{M_L}}{\sqrt{(K_1 - n^2\omega^2)^2 + n^2\omega^2 f_1^2}};$$

Expanding,

$$D_n = \frac{\frac{F_n}{M_L}}{\sqrt{\left[\left(\frac{1}{M_L} + \frac{1}{M_T}\right)K - n^2\omega^2\right]^2 + \left(\frac{1}{M_L} + \frac{1}{M_T}\right)^2 n^2\omega^2 f^2}} \quad . \quad (5)$$

In the case of oscillations arising from unbalanced reciprocating parts, $n = 1$ and $F = \pm\sqrt{2}\frac{W\omega^2 r}{g}$

Writing W_L and W_T for M_L and M_T, the values of g cancel out, and

$$D_1 = \pm \frac{\sqrt{2}Wr\omega^2}{W_L\sqrt{\left[\left(\frac{1}{W_L}+\frac{1}{W_T}\right)K - \omega^2\right]^2 + \left(\frac{1}{W_L}+\frac{1}{W_T}\right)^2\omega^2 f^2}} \quad . \quad . \quad (6)$$

APPENDIX IV.

Amplitude of Oscillations D_2 Due to Steam-Pressure.

The amplitude of oscillations due to steam-pressure is also derived from equation (5), but in this case $n = 4$, and F_4 is the fluctuation in drawbar pull due to variation in steam-pressure during the piston-stroke.

Thus the value of the amplitude is

$$D_2 = \pm \frac{F_4}{W_L\sqrt{\left[\left(\frac{1}{W_L}+\frac{1}{W_T}\right)K - 16\omega^2\right]^2 + \left(\frac{1}{W_L}+\frac{1}{W_T}\right)^2 16\omega^2 f^2}} \quad . \quad (7)$$

APPENDIX V.

Maximum Values of D_1 and D_2 Due to Resonance.

(*a*) For D_1, $n = 1$; and if $\frac{1}{W_L} + \frac{1}{W_T} = \frac{1}{S}$, equation (5) becomes

$$D_1 = \frac{\frac{SF_1}{ML}}{(K - S\omega^2)^2 + \omega^2 f^2}$$

Force F_1 varies as ω^2; so F_1 may be written as $C\omega^2$, where C is a constant depending on the dimensions of the locomotive and given by the expression $\frac{\sqrt{2}Wr}{g}$.

$$\text{Therefore } D_1 = \frac{\frac{CS\omega^2}{W_L}}{\sqrt{(K - S\omega^2)^2 + \omega^2 f^2}}$$

The amplitude, considered as a function of ω, has a maximum value when

$$\frac{dD_1}{d\omega} = 0.$$

After differentiating and solving the resultant equation, it is found that the required value of ω is given by

$$\omega = \sqrt{\frac{2K^2}{2KS - f^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and that the value of this maximum amplitude

$$D_1\,(\text{max.}) = \pm \frac{S}{W_L} \times \frac{2KC}{f\sqrt{4KS - f^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

(*b*) For D_2, $n = 4$; and if $\frac{1}{W_L} + \frac{1}{W_T} = \frac{1}{S}$, as above,

$$D_2 = \frac{\frac{SF_4}{W_L}}{\sqrt{(K - 16S\omega^2)^2 + 16\omega^2 f^2}}$$

The variation of the force F_4 is not a very well-defined function, depending, as it does, on speed, on mean tractive effort, and on the manner in which the locomotive is worked. It can be seen, in general terms, that resonance due to the action of F_4 can occur only at a low speed, and in these circumstances F_4 may be assumed, in a representative case, to be $\pm$ 2 tons.

Using, as before, the relation $\frac{dD^2}{d\omega} = 0$,

the maximum value of D_2 occurs when

$$\omega = \sqrt{\frac{2KS - f^2}{2S^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and is of magnitude

$$D_2\,(\text{max.}) = \pm\frac{S}{W_L} \cdot \frac{2SF_4}{f\sqrt{4KS - f^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Paper No. 5270.

"A Laboratory Study of London Clay." †

By Leonard Frank Cooling, M.Sc., and Alec Westley Skempton, M.Sc., Assoc. M. Inst. C.E.

(*Ordered by the Council to be published with written discussion.*)[1]

TABLE OF CONTENTS.

Introduction.

London Clay is the principal geological formation in the London district and is of considerable engineering importance, as being the stratum on which many large buildings and bridges are founded and through which

[1] Correspondence on this Paper can be accepted until the 15th April 1942, and will be published in the Institution Journal for October 1942.—Sec. Inst. C.E.

the greater part of the tube railways are driven. In a few localities the full thickness of the bed is present and is found to be between 300 feet and 430 feet. Under London itself the formation has undergone considerable erosion and in the City is now only between 85 feet and 130 feet in thickness. It belongs to a type known as "stiff fissured" clays[1] and is slightly laminated. Normally it has a dark bluish-grey colour but, in the surface layers, oxidation of ferrous to ferric salts changes its colour from blue to brown. In some regions this zone of oxidation has been proved to a depth of 40 feet. This Paper, however, is concerned only with the blue London Clay.

During the course of an investigation relating to the foundations of the new Waterloo bridge, carried out in 1938 and 1939, the Building Research Station had the opportunity of examining and testing a large number of samples of blue London Clay taken from various depths beneath the foundation-level of the piers and abutments. This work enabled a detailed study to be made of the variation in the properties of the clay in both vertical and horizontal directions over a fairly extensive site. This detailed study was made with the following objects in view.

In civil engineering problems the properties of the soil which chiefly require investigation are those which govern its reaction to stress changes. These mechanical properties comprise two main groups: (i) those relating to consolidation (volume decrease under load), and (ii) those which govern the resistance to deformation under shear stresses. The study of consolidation is mainly of importance in relation to settlement problems, whilst the investigation of shearing resistance is chiefly required for the analysis of stability problems. The estimation of the probable behaviour of the soil in a particular case is based on consolidation or shear characteristics measured by tests on samples in the laboratory. This dependence on samples, however, inevitably introduces certain difficulties.

In the first place all natural soils exhibit variations even over short distances of a foot or so. Thus in order to assess how far the characteristics measured by tests on a limited number of samples can be taken as representative of a complete soil profile, it is necessary to have some measure of the degree of variation to be expected in a given stratum. The results given in the present Paper indicate the degree of variation found in the London clay stratum. Consolidation tests in particular are lengthy and expensive, so that it is impracticable in most problems to test more than a few samples. Fortunately supplementary tests known as "index-property" tests are available which are very simple to carry out. Since the results obtained with them depend upon two factors, the composition and water-content of the soil, which together with the structure of the soil govern its mechanical properties, they may be expected to give at least an indication of the variation in the mechanical properties. If correlations

---

[1] The references are to the bibliography on page 275, *post*.

can be established between these two groups of tests, it then becomes possible to use the simple tests to explore in detail the variation in the mechanical properties of the soil. It was one of the objects of the present work to see how far relationships could be established with the samples of London Clay from this site.

The present Paper accordingly describes the results of the index-property tests determined on a comparatively large number of samples. Tentative correlations obtained between the consolidation characteristics and the index properties are given, and their use in estimating representative values for a given soil profile is illustrated. Shear tests and their correlation with the index-properties are next considered, but in less detail than the consolidation tests.

A second difficulty involved in the use of samples is that in the process of sampling the condition of the soil is altered from that at which it existed in the ground. The degree of disturbance depends a good deal on the technique of sampling, but in obtaining the "undisturbed" samples referred to in this paper care was taken to keep disturbance to a minimum.

A third point is that certain constructional operations, such as pile driving, may disturb the condition of the soil in the ground to an appreciable extent and it is difficult to obtain samples which will reveal these changes. London clay, with its fissured structure, is likely to be particularly sensitive to such disturbance, the opening up of the fissures and subsequent softening of the soil in contact with water tending to alter the properties to an important extent. This problem is outside the scope of the present Paper, but it is mentioned here since with sites on London clay where constructional operations may cause disturbance of the soil, the resulting change in properties may be such as to give values for the soil characteristics outside the range quoted in the Paper.

The Soil Samples.

The samples of clay on which the investigations were carried out were obtained, by Messrs. Le Grand, Sutcliffe and Gell, Ltd., from six boreholes, about 250 feet apart, sunk to a depth of 40 feet beneath the foundation-level of the four piers and two abutments of the bridge. Records of well borings [2] in the neighbourhood show that the London Clay extends from — 18 O.D. to — 115 O.D., and since the foundation-level of the piers is — 35 O.D. and that of the abutments is — 25 O.D., the portion of the stratum examined was that extending from 40 feet to 90 feet above the bottom of the bed.

Two types of samples were obtained, namely, "undisturbed" samples and subsidiary samples consisting of pieces of disturbed clay taken from the auger. The undisturbed samples, which were the more important, were obtained by a sampling-tube of simple design[3]. Briefly the procedure was as follows: excavation for the foundations proceeded in open

cofferdams of steel sheet-piling, and boring was commenced when only a few feet of clay was left to be removed before reaching foundation-level. A hole 6 inches in diameter was augered and lined, using a hand derrick erected on temporary staging placed on the lowest setting of struts. Undisturbed samples, $4\frac{1}{4}$ inches in diameter and 15 inches long, were taken at intervals of about 6–8 feet and subsidiary samples at intermediate positions 2 feet apart. For obtaining the undisturbed samples the sampling-tube was driven into the clay by percussion. The undisturbed samples were coated with paraffin wax immediately after removal from the tube, and the subsidiary samples were packed into airtight jars, in order to minimize the loss of water by evaporation. The term "undisturbed" is a relative one, for some disturbance due to driving the sampling tube into the clay is inevitable; this was evident from the distortion of the laminations which was, however, found to be limited to the outer $\frac{1}{4}$ inch of the sample. This does not necessarily imply that the remainder of the sample is entirely undisturbed, but it does indicate that the sampling technique was reasonably satisfactory. The degree of disturbance caused by sampling is, of course, important and, since it depends upon the design of the tube, as well as upon the sampling technique, the principal dimensions of the tube are given. The greatest external diameter was $4\frac{5}{8}$ inches, the internal diameter of the cutting-nose was $4\frac{3}{16}$ inches, and the internal diameter of the tube was $4\frac{1}{4}$ inches. The displacement of soil when the tube is driven into it is proportional to $\frac{\pi}{4}(4{\cdot}63^2 - 4{\cdot}19^2)$, and the ratio of this area to that of the cross section of the sample $\frac{\pi}{4}(4{\cdot}19^2)$ is designated the "area-ratio." The lower this ratio the more satisfactory is the design[4]. For the tube used in this work the ratio was 22 per cent., a value which compares favourably with that for many tubes now in use.

Fifty undisturbed samples were taken, and in spite of the friable nature of the clay it was possible to prepare test specimens from all but four of these. The number of subsidiary samples taken was 117.

Laboratory Examination.

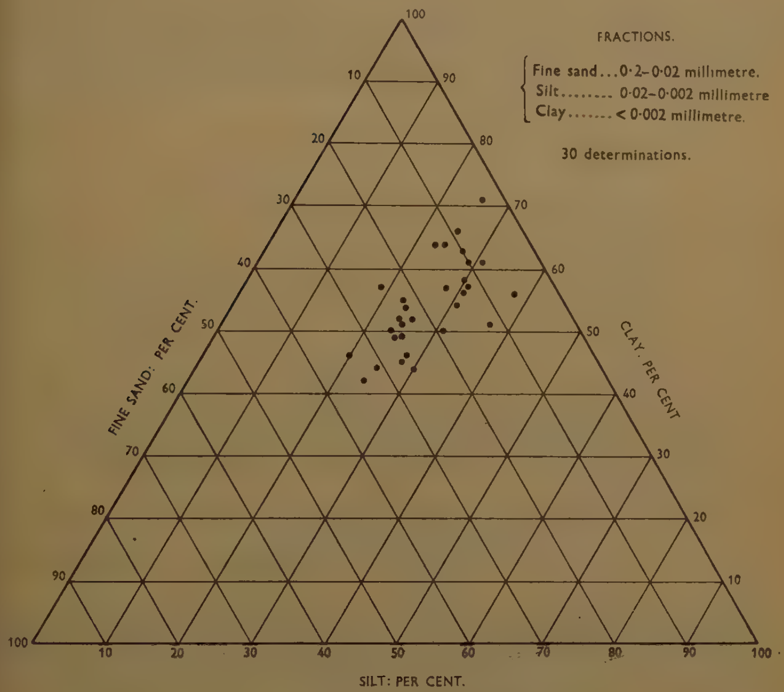
In the laboratory the mechanical properties of the clay were determined by tests on undisturbed samples only, owing to the fact that the structure of the clay has an important influence upon these properties. Index-property tests were not subject to this restriction.

Description of the Clay.

Visual examination during sampling and preparation of specimens for test showed that the clay consisted of a stiff dark blue-grey clay with laminations and with occasional small lenses of fine sand, less than 1 millimetre in thickness. Minute crystalline flakes of selenite were abundant

and iron pyrites occurred both in crystal clusters and as casts of fossil wood. Occasional small broken shells were the only fossils encountered. A very important structural feature of the clay was the presence of a network of incipient planes of weakness, the orientations of which were apparently at random and bore no relation either to the bedding or to the laminations. This caused the clay to be very friable and to break up readily into polyhedral fragments. Clays of this type have been described by Professor Karl von Terzaghi, M. Inst. C.E., as "stiff-fissured" clays [1].

Fig. 1.



Particle Size Distribution.

Some samples were more silty than the remainder, but in general the clay appeared moderately homogeneous. However, visual examination is not sufficient to indicate the degree of variation quantitatively. A direct method of establishing the degree of variation quantitatively is to determine, by means of the mechanical analysis test, the proportions of the variously-sized particles of which the soil is composed. Mechanical analyses were carried out on thirty samples, and it was found that none had more than 1 per cent. coarse sand. The percentages in the remaining three fractions can, therefore, be expressed in the triangular diagram shown

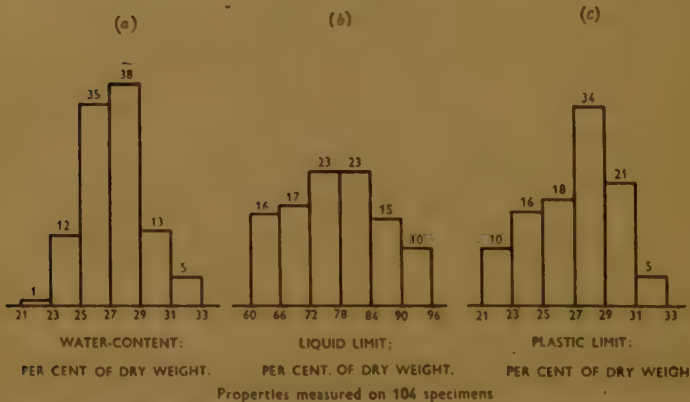
in *Fig. 1*. This indicates that clay fraction ranges from 42 per cent. to 71 per cent. by weight of the total sample: this is a significant variation, representing a change from a silty clay to a "fat" clay.

Index-Property Tests.

The index-property tests comprise a series of tests which are not only simple to carry out but also reflect closely the variations in composition and consistency of a soil. They include the following: the natural water-content, the Atterberg limits ("liquid limit" and "plastic limit"), and the unconfined compression test. The latter test is used mainly as an index of shearing resistance, but in stiff-fissured clays the difficulty of obtaining satisfactory specimens for test prevents its wide use.

The natural water-content is the water-content of the clay as it exists in the ground. It is determined by measuring the loss in weight of a small weighed specimen after drying to constant weight in an oven at 105° C. The result is expressed as a percentage of the dry weight. This test is very simple to carry out and is, in general, one of the most useful index tests. Thus in the recent investigation on the Chicago Subway soils [5] it was used very extensively in studying variations, together with the compressive strength.

Figs. 2.



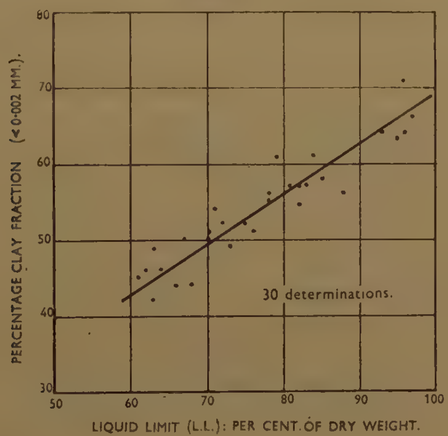
FREQUENCY DIAGRAMS OF WATER-CONTENT, LIQUID LIMIT, AND PLASTIC LIMIT.

The results of the present series of tests are given in the form of a frequency-diagram in *Figs. 2 (a)*. The mean natural water-content is 26·6, and the distribution of values is approximately normal, with a standard deviation of $\pm$ 2·1. About two-thirds of the samples are, therefore, included in the range from 24·5 to 28·7, and the total range, including all samples, is from 22·6 to 31·8.

The liquid limit is the water-content (expressed as a percentage of the

dry weight) required to bring the clay to a consistency at which it will flow on being subjected to small mechanical shocks. It is determined by means of an internationally standardized apparatus, originally developed by Dr. A. Casagrande [6] to whose Paper reference should be made for details of the test. This soil constant, although arbitrary, is very useful, since it is governed to an important extent by the composition of the soil. This point is illustrated in *Fig. 3*, which indicates a linear relation between the liquid limit and the percentage of clay fraction, for those samples on which mechanical analyses were carried out. In passing, it may be mentioned that the percentage of clay fraction is the feature of soil composition which has the most important influence upon the foundation properties of a clay soil.

Fig. 3.



The results of the liquid-limit tests are given in the form of a frequency diagram in *Figs. 2* (*b*). The mean value is 76·6, with a standard deviation of $\pm$ 9·2 and a total range of from 60 to 96.

The plastic limit is the water-content at which the soil ceases to exhibit plastic properties and becomes friable. It is determined by a standard technique[6], and is defined as the water-content at which it is just not possible to roll the soil into threads of $\frac{1}{8}$ inch diameter without their breaking. This constant is also influenced by the composition, but not to the same extent as the liquid limit.

The mean value of the plastic limit is 26·6, with a standard deviation of $\pm$ 2·6 and a total range of 21·4 to 32·4. The variation is shown in *Figs. 2* (*c*).

The difference between the liquid and the plastic limit of a soil is a measure of the range of water-content over which it possesses plastic properties, and is designated the plasticity-index. The relation between

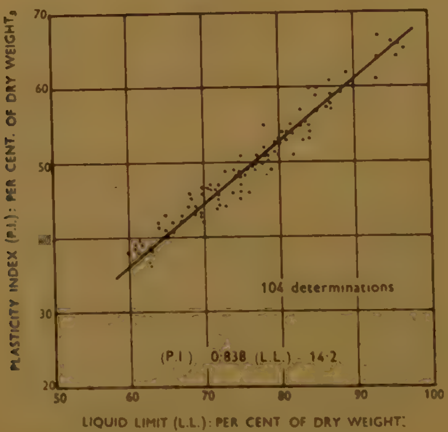
liquid limit and plasticity-index, which is often quoted in soil mechanics reports, is given for London Clay in *Fig. 4*. The correlation is close and shows that for any given liquid limit the plastic limit lies within a comparatively small range. This affords a useful means of checking individual determinations.

The consistency of a soil is indicated by the magnitude of the water-content relative to the liquid and plastic limits, and is usually expressed as the liquidity-index, defined as :—

$$\text{Liquidity-index} = \frac{\text{water-content} - \text{plastic limit}}{\text{liquid limit} - \text{plastic limit}}.$$

When the natural water-content equals the liquid limit the liquidity-

Fig. 4.



index becomes equal to unity ; this is approximately the state of a freshly-deposited sediment. As the soil becomes tougher the index falls, until at zero the natural water-content equals the plastic limit, and this corresponds to a highly-consolidated sediment. This is the case with London Clay, the average liquidity-index of which is zero.

Turning now to the use of the index properties in studying the variation of London Clay, the first step is to determine the variation over short distances. The importance of this was first suggested to the Authors by Professor von Terzaghi during his visit to England in 1938. The index properties were determined at intervals of 2 inches down the length of two undisturbed samples ; the results are given in Table I.

These results show that within a depth of only a few inches there are changes in the index properties amounting to about one-third of the total range of values ; for example, in sample 72/2/a the liquid limit ranges from 60 to 72, in comparison with the range 60–96, given in *Figs. 2 (b)*. That

TABLE I.

Distance from top of sample: inches.	Sample 72/2/a.			Sample 72/S/f.		
	Water-content: per cent. of dry weight.	Liquid limit: per cent. of dry weight.	Plastic limit: per cent. of dry weight.	Water-content: per cent. o dry weight	Liquid limit: per cent. of dry weight.	Plastic limit: per cent. of dry weight.
2	24	71	24	27	78	28
4	24	70	24	28	73	24
6	22	60	22	28	80	27
8	24	61	22	24	75	27
10	25	67	24	25	83	26
12	25	72	25	24	81	27

such a variation should exist is not surprising for, as Terzaghi [7] has pointed out, the lithology of a sediment depends upon the conditions, such as currents and source of origin of the particles, which obtained at the period of deposition, and these are subject to both seasonal and progressive changes. The point is emphasized by the fact that the deposition of sediments is an extremely slow process, recent estimates [8] of the rate of deposition of near-shore sediments being 1 foot in 700–1,000 years.

The variation over the full depth of a borehole is illustrated in *Fig. 5*. An examination of the liquid limit down this soil profile shows that over distances of many feet the variation does not exceed that found in a few inches. Thus between — 36 O.D. and — 44 O.D. there is a comparatively silty zone in which all the liquid limits lie in the range 63–70. Similarly in a zone between — 44 O.D. and — 71 O.D. the range is from 70 to 84.

Although the data in *Fig. 5* suggest that it might be more accurate to split the profile into smaller zones with smaller ranges of liquid limit, yet the evidence of the single samples shows this to be unjustifiable.

The other boreholes yielded results similar to those in *Fig. 5*, and showed that, apart from changes of a few feet in the level and thickness of the silty zone, there were no considerable variations in a horizontal direction.

It appears, therefore, that although the clay exhibits marked changes in properties over very small thicknesses, yet during the deposition of many feet of clay the conditions did not alter sufficiently to exceed these changes. It will be seen later that this has practical significance in the estimation of representative values of the consolidation characteristics of the clay.

In the boreholes below the abutments it was found that the clay above the silty zone was very similar to that below it; thus there is no general tendency for the clay to become increasingly silty towards the surface.

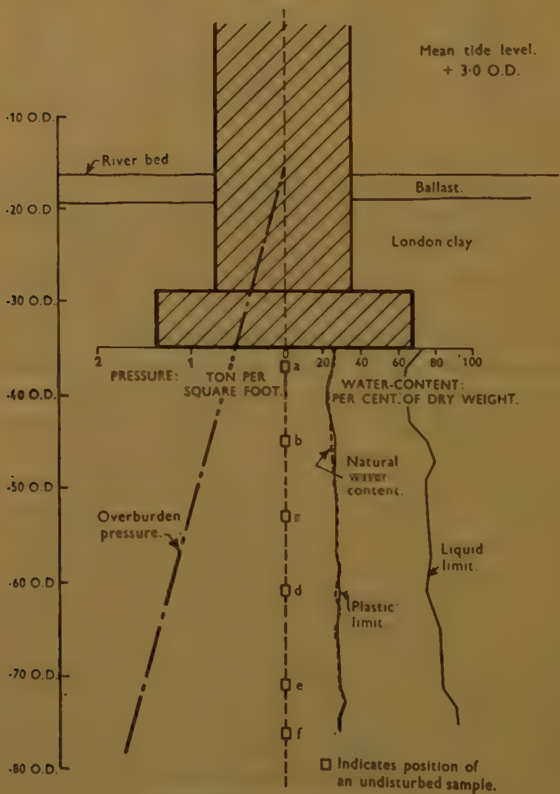
Consolidation Tests.

The principal two characteristics indicated by the consolidation test are the compressibility and the coefficient of consolidation of the soil. Know-

ledge of these renders it possible to estimate the settlement of a structure founded on the soil, when the settlement is due to consolidation[9]. The compressibility is the factor controlling the final settlement, and the coefficient of consolidation controls the progress of settlement with time.

Consolidation tests were carried out, in the standard oedometer apparatus, on forty-six of the undisturbed samples. The procedure in

Fig. 5.



PROFILE AT PIER 1.

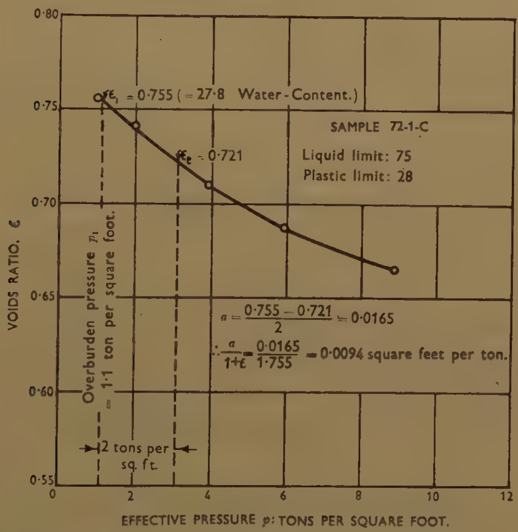
the test and the method of determining the consolidation characteristics from the test results have been described elsewhere[10]. Only two special points need to be mentioned. The first is that the specimens used were 3 inches in diameter and ¾ inch thick, the outer ½ inch of the sample from the boring, which includes the disturbed portion, being discarded. The second point is that the initial pressure applied to the specimens was 1 ton per square foot, which corresponds roughly to the overburden pressure on the samples when in the ground. In most specimens the

movements under this pressure were small. The pressure was then increased successively to 2, 4, 6, and 9 tons per square foot.

It was found that an approximately steady state was attained after each increment had been maintained for 24 hours; and in three cases wherein an increment was maintained for 72 hours the average compression-movement during the last 48 hours was 5 per cent. of that which occurred during the first 24 hours.

A typical curve showing the decrease in voids-ratio with increasing effective pressure p is given in *Fig. 6*. Taking $a = -d\epsilon/dp$ = the slope of the curve at any given voids-ratio ϵ, the compressibility of the clay at

Fig. 6.



TYPICAL PRESSURE-VOIDS RATIO CURVE.

this voids-ratio is $\dfrac{a}{1+\epsilon}$. The compressibility is, therefore, a function of pressure. In this investigation a is taken as the average slope of the p/ϵ curve over the range of pressure p_1 (the overburden pressure) to $(p_1 + 2)$ tons per square foot, and ϵ denotes the voids-ratio corresponding to p_1.

Of the forty-six specimens two had compressibilities considerably greater than the remainder. As they were both from samples taken immediately below the surface exposed at the bottom of the cofferdam, it was concluded that the clay had been able to swell in contact with water, and the results were, therefore, rejected. The mean compressibility of forty-four specimens was found to be 93×10^{-4} square feet per ton with a total range of 63×10^{-4} square feet per ton to 120×10^{-4} square feet per

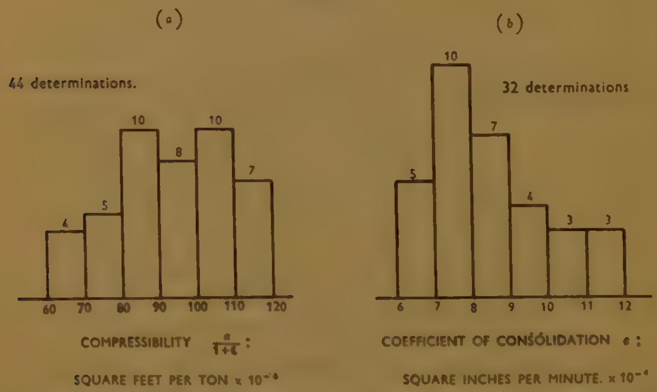
20

ton. The variation is expressed as a frequency-diagram in *Figs. 7* (*a*) and the standard deviation is $\pm 16 \times 10^{-4}$ square feet per ton.

The value of compressibility given above is, from a practical point of view, tending to a lower limit. The upper limit is obtained by taking a as the slope of the p/ϵ curve at the overburden pressure, and this gives a mean value of 103×10^{-4} square feet per ton. The limits are sufficiently close to enable a working value of 100×10^{-4} square feet per ton to be used for the compressibility without any serious error.

As an indication of the influence of the soil structure, it may be mentioned that the compressibility is approximately doubled if the clay is remoulded at its natural water-content, whilst an even greater increase

Figs. 7.



Frequency Diagrams of Compressibility and Coefficient of Consolidation

may result from the clay being allowed to swell and soften in contact with water.

Fig. 8 shows a time-consolidation curve in which the degree of consolidation is plotted against the square root of the time t after the application of the pressure increment. In these tests the degree of consolidation μ is calculated with reference to the compression which has taken place at the end of 24 hours. In the first half of the consolidation process the relation between μ and $\sqrt{t}$ is linear. This is in accordance with Terzaghi's theory of consolidation; and the theoretical curve with the same initial slope as the experimental curve is shown dotted. The moderately close correspondence of these two curves shows that the "secondary compression" [11] is not large; consequently the coefficient of consolidation of the clay has been calculated by the following simple method.

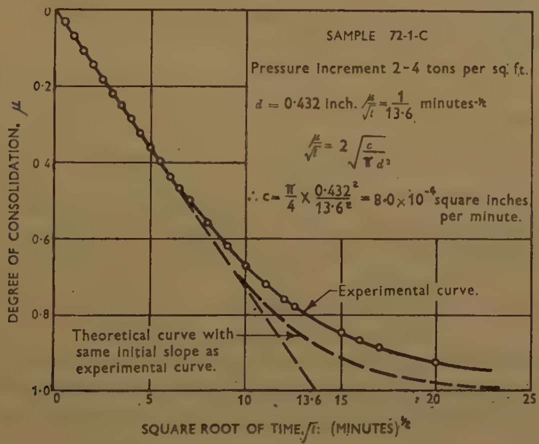
From the theory of consolidation it can be shown that in the range $0<\mu<0{\cdot}5$ the relation between μ and $\sqrt{t}$ is linear to a very high degree of accuracy, and that the slope of this linear portion is :—

$$\frac{\mu}{\sqrt{t}} = 2\sqrt{\frac{c}{\pi d^2}}$$

where c is the coefficient of consolidation, and d denotes the "drainage-path" of the specimen, which is one-half its thickness. The experimental value of $\mu/\sqrt{t}$ is known, and also the value of d; hence the value of c can be calculated.

The calculation of c for the results of *Fig. 8* is given in the Figure, and the coefficients for the four pressure-increments on this specimen are given in Table II.

Fig. 8.



TYPICAL TIME-CONSOLIDATION CURVE.

TABLE II.

Pressure increment: tons per square foot.	Coefficient of consolidation: square inches per minute.	
1–2	$8{\cdot}4 \times 10^{-4}$	Mean $= 8{\cdot}4 \times 10^{-4}$
2–4	$8{\cdot}0 \times 10^{-4}$	
4–6	$8{\cdot}3 \times 10^{-4}$	
6–9	$8{\cdot}9 \times 10^{-4}$	

The agreement between the experimental and theoretical time-consolidation curves was not always so close as that shown in *Fig. 8*. The most important discrepancy was a failure to exhibit a strictly linear initial portion, the graph showing a gradual curve throughout; with fourteen of the specimens the complete set of time-consolidation curves for the four pressure-increments showed this discrepancy. Had it been necessary, an approximate value could have been obtained, as the discrepancies were

not large, but the remaining thirty-two specimens gave a total of ninety-nine curves agreeing with theory to an extent equal to that shown in *Fig. 8.*

The mean value of the coefficient of consolidation for each of these thirty-two specimens was found ; the results are expressed as a frequency-diagram in *Figs.* 7 (*b*). The mean is $8{\cdot}5 \times 10^{-4}$ square inches per minute, with a standard deviation of $\pm 1{\cdot}5 \times 10^{-4}$ square inches per minute, and a total range from $6{\cdot}4 \times 10^{-4}$ to $11{\cdot}7 \times 10^{-4}$ square inches per minute.

In order to detect any significant change in the coefficient with increase in pressure, an average value was obtained for the results of the thirty-two specimens at each pressure-increment. The results, which are given in Table III, indicate that over the pressure-range the coefficient is approximately constant.

TABLE III.

Pressure increment: tons per square foot	1–2	2–4	4–6	6–9
Coefficient of consolidation: square inches per minute	$9{\cdot}1\times10^{-4}$	$8{\cdot}3\times10^{-4}$	$8{\cdot}0\times10^{-4}$	$8{\cdot}9\times10^{-4}$

No complete explanation can be given for the fact that the initial linear portion was absent in some of the time-consolidation curves, although it seems likely that it was at least partly due to the inclusion of air in the samples. The average compressibility of the fourteen specimens was found to be within 2 per cent. of that of the thirty-two specimens, the curves of which agree with theory.

The results given above were obtained by a simple method in which the secondary compression is neglected. However, the coefficients of consolidation were also calculated by methods which make a correction for this effect. These methods have become standard practice in soil mechanics laboratories in America ; the results are given here principally for purposes of comparison.

The effective coefficient of consolidation, as calculated by the method [11] in use at the Massachusetts Institute of Technology, was found to have a mean value of 10×10^{-4} square inches per minute, and the primary compression-ratio had a mean value of 0·85, with an actual range from 0·72 to 0·96. Neither characteristics showed any significant variation with pressure. The Harvard method [12] requires that the pressure-increments be maintained for at least 2 days, and preferably 3 days, in order that the secondary compression may be clearly defined. In the three cases in which this method was used, the average result was only slightly lower than that obtained by the Massachusetts Institute of Technology method as applied to the same curves. It was, therefore, concluded that the mean coefficient of consolidation, as calculated by the method described in the

Paper, is 15 per cent. less on the average than the value obtained by correcting for secondary compression. From the practical point of view, however, this discrepancy is not serious.

The compressibility and coefficient of consolidation of some other clays and silts are given in Table IV in order that the values obtained for London Clay, and their degree of variation, may be seen in relation to the range of values obtained for different soils.

TABLE IV.

Soil.	Depth below surface : feet.	Index properties : per cent. of dry weight.			Compressibility over range p_1 to (p_1+1) : square feet per ton.	Coefficient of consolidation : square inches per minute.
		Water-content.	Liquid limit.	Plastic limit.		
London Clay, Waterloo bridge . .	45	27	77	28	100×10^{-4}	10×10^{-4}
Compact silty clay, Calcutta . . .	120	28	60	22	60×10^{-4}	120×10^{-4}
Solft blue silty clay, Weston-super-Mare	15	37	49	24	450×10^{-4}	20×10^{-4}
Soft grey silt, near Glasgow . . .	5	26	36	20	280×10^{-4}	180×10^{-4}

p_1 denotes overburden pressure.

Bearing in mind that the compressibilities are proportional to the final settlement of a soil layer and that, in the early stages of consolidation, the settlement, expressed as a percentage of the final settlement, is roughly proportional to the square root of the coefficient, the following general conclusions may be derived from Table IV by way of illustration.

Whereas the final settlement of the Calcutta silt is about one-half that of London Clay, the rate of settlement is about three or four times as great. On the other hand, the rate of settlement of the Weston clay is only slightly greater than that of London Clay, although its compressibility is more than four times as great. The soft Glasgow silt is not only nearly three times as compressible, but also the rate of settlement is more than four times as great.

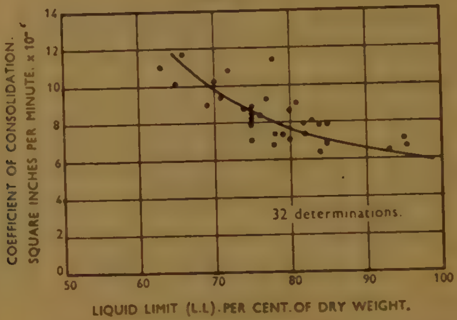
Correlation Between Consolidation Characteristics and Index Properties.

As already pointed out, both the index properties and the mechanical properties depend upon the composition and consistency of the soil.

In *Fig. 9* the coefficient of consolidation has been plotted against liquid limit. The latter was determined on pieces of clay taken from the undisturbed samples in the immediate neighbourhood of the consolidation test specimens. The correlation between these quantities is reasonably close, the range of values of the coefficient, for any value of liquid limit,

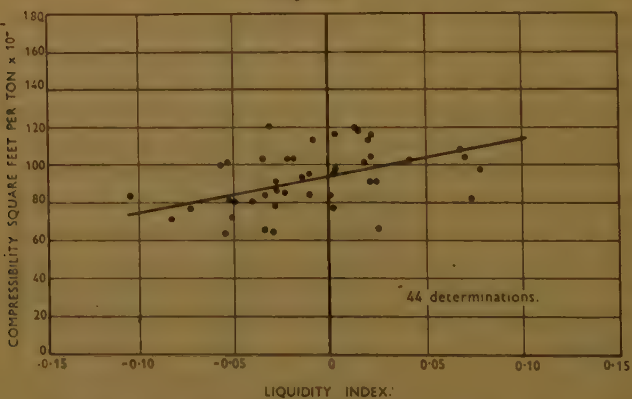
being about $\pm$ 10 per cent., and it is considered that it represents an important relationship for London Clay.

Fig. 9.



From general considerations it might be anticipated that the compressibility would be related to the consistency of the soil. The consistency is indicated by the liquidity-index, but a close correlation was not expected in this particular series of tests, owing to the uncertainties in determining the differences between the water-content and plastic limit. The correlation is given in *Fig. 10*, and is significant, although there are very considerable individual discrepancies.

Fig. 10.



The use of these correlations in obtaining representative values of the consolidation characteristics is exemplified by the soil profile given in *Fig. 5*. As previously mentioned, all the samples within zones of several feet in thickness lie within a range of liquid limit not exceeding that found in a depth of 1 or 2 inches. This range is about one-third of the total and from the correlation it will be seen that this corresponds to a variation in the coefficient of consolidation of about 20 per cent. This is not larg

from the practical point of view, and each zone can, therefore, be considered as consisting of one type of soil with a constant value of the coefficient, corresponding to the average liquid limit of the zone. The values taken from *Fig. 5* are given in Table V. The close correspondence between the natural water-content and the plastic limit in this borehole results in an almost constant value for the compressibility.

TABLE V.

Elevation : feet.	Depth : feet.	Average liquid limit : per cent. of dry weight.	Average liquidity index.	Coefficient of consolidation : square inches per minute.	Compressibility : square feet per ton.
– 36 O.D. to – 44 O.D. .	8	66	+0·01	$11{\cdot}2 \times 10^{-4}$	96×10^{-4}
– 44 O.D. to – 71 O.D. .	27	78	– 0·005	$8{\cdot}0 \times 10^{-4}$	93×10^{-4}
– 71 O.D. to – 75 O.D. .	4	88	about 0	$6{\cdot}6 \times 10^{-4}$	94×10^{-4}

This method of dividing the soil profile into zones on the basis of the liquid-limit values was also applied to the other boreholes. A silty zone, with liquid limits less than 70 per cent., was found in each one ; in this zone the liquidity index was positive, in contrast to the negative values found in the remainder of the clay. In the various boreholes, from two to four zones were recognized. The coefficient of consolidation gave values of the same order as those in Table V, and the range of variation was similar. In each borehole the compressibility showed little variation down the profile.

Although the correlations given in *Figs. 9* and *10* are not close, it is considered that the use of the index properties has resulted in a more reliable representation of the consolidation characteristics than could have been obtained with the undisturbed samples alone.

Strictly these correlations apply only to the samples from the actual site, and it is realized that with an extensive deposit such as the London Clay, there may be localities where the properties of the clay lie outside the range encountered in this investigation. However, tests which have been carried out during the past 6 years on samples from different sites have given values within this range. The results are summarized in Table VI.

TABLE VI.

Site.	Approximate position of sample above bottom of stratum : feet.	Natural water-content : per cent. of dry weight.	Liquid limit : per cent. of dry weight.	Plastic limit : per cent. of dry weight.
Chingford	40	29	77	27
Liverpool Street Station	70	27	84	26
Southwark	90	29	68	24
Earl's Court	160	29	97	27
Kensal Green	210	28	81	28

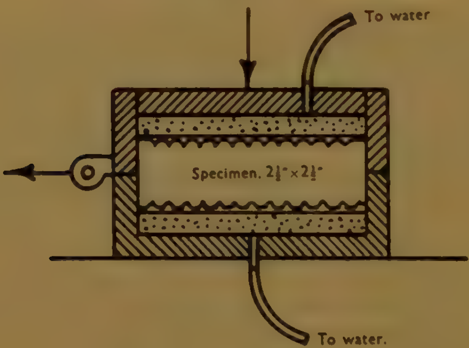
The results given above apply to the blue London Clay. The brown London Clay usually has a higher natural water-content and, as there has not yet been any occasion for carrying out a series of consolidation tests on this material, it is not known whether the correlations will apply.

Shear Tests.

The shear strength of soils is of importance in problems relating to the stability of footings and of embankments and cuttings.

In the tests described below the relation between the shear strength and the effective normal pressure acting on the plane of failure was determined in the shear box apparatus. The test-specimen was carefully cut from the undisturbed sample and placed in the box between toothed grids and porous stones, as shown in *Fig. 11.* A vertical load was then

Fig. 11.



SHEAR BOX.

applied and allowed to remain in position for 24 hours, after which time the specimen had come to equilibrium. A horizontal force was then applied and increased in small steps until failure occurred.

Vertical pressures of 0, 1, 2, and 3 tons per square foot were applied to each of the four specimens prepared from ten undisturbed samples; the mean values of the results are plotted in *Fig. 12.* The increase in strength with increase in pressure is due both to an increase in cohesion following the decrease in water-content and to friction between the soil particles.

The individual results for the series of tests at 1 ton per square foot are given in *Fig. 13*, wherein they have been plotted against the liquidity index; similar results were obtained with the other pressures. A correlation is evident, and this provides a reasonable justification for the use of the liquidity-index as an indication of the consistency of clays. The average liquidity-index of the ten samples tested in shear was slightly

higher than the average for the site: this means that the shear strengths shown in *Fig. 12* are slightly lower (by about 5 per cent.) than would be expected from the average of the complete site.

In different practical problems two values of shear strength need to

Fig. 12.

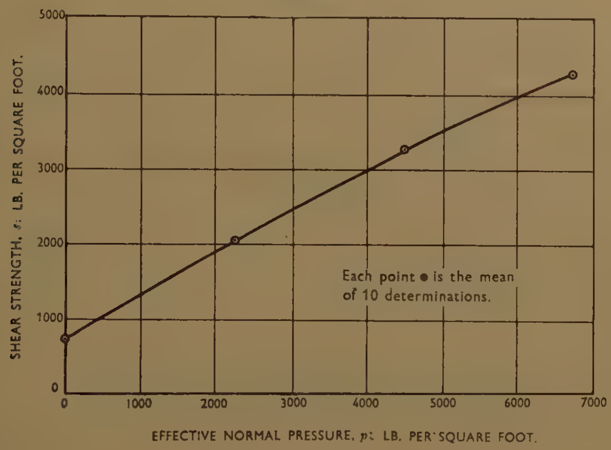
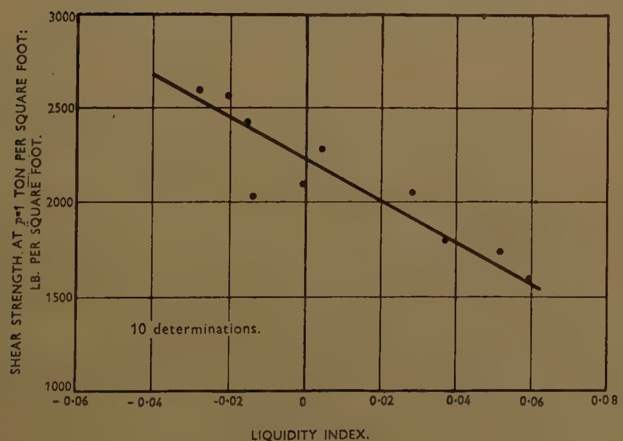


Fig. 13.



be considered. In problems relating to the stability of foundations the strength of the clay as it exists in the ground is required. In some deposits this is the strength corresponding to the overburden pressure: but in a highly consolidated sediment, such as London Clay, there may be important

residual lateral pressures[13], and the strength of the clay may not be directly related to the overburden pressure. The problem requires further investigation, and its discussion lies outside the scope of this Paper.

In problems relating to the stability of cuttings in stiff fissured clays the shear strength corresponding to zero normal pressure is required; for when a cutting is excavated, the fissures in the clay tend to open up and, as the clay is strong, they may remain open to considerable depths. Water will then filter into the fissures and produce a softening of the clay. The lowest value of the shear strength in the fissure is, therefore, that corresponding to zero normal pressure. In the tests this shear strength was about 780 lb. per square foot. The softening proceeds progressively throughout the mass of clay, and may result finally in a slip in the cutting, which may occur even 50 years after the cutting was excavated.

This explanation of the mechanism of slips in cuttings in stiff fissured clays, the original strength of which is greatly in excess of that required for stability, was first suggested by Terzaghi[1], and was discussed in relation to the Herne Bay cliffs by Mr. George Ellson, M. Inst. C.E., and Mr. L. F. Cooling[14].

Another means of investigating the shear strength of clays is the unconfined compression test. In soft clays the test can be readily carried out, and as, in such soils, there is a direct relation between compressive and shear strength, it is used as an index property, as previously mentioned. At the Building Research Station a portable apparatus[15] has been developed, which, in conjunction with a small sampling-tube of 1½ inch diameter, enables tests to be readily carried out in the field. With stiff fissured clays, however, the test is less useful, owing to the difficulty experienced in obtaining and preparing satisfactory test-specimens, and to the uncertain relation between shear and compression strength.

Compression tests were carried out on twenty-three specimens, prepared from ten undisturbed samples, and these were protected from evaporation during testing. Observations of deformation were taken with increasing load until failure occurred, when the specimen sheared along one or more diagonal planes.

The modulus of deformation was taken as the tangent of the initial slope of the stress-strain curve, and was found, within close limits, to be seventy times the compressive strength.

The mean compressive strength was 6,600 lb. per square foot, with a range of from 4,000 to 10,000 lb. per square foot. The mean modulus of deformation was 470,000 lb. per square foot.

The relation between the compressive strength and the liquidity-index was examined; although the correlation was not close, the tendency was for the strength to decrease with increase in liquidity-index.

Although an insufficient number of samples was tested to allow of definite conclusions, the results suggested that the ratio of the shear strength to the compressive strength was not a constant, but decreased

from one-half to something less than one-third as the compressive strength increased from its lower limit to its upper limit.

Miscellaneous Tests.

The results of three further series of tests carried out on a few samples are summarized for purposes of record.

The first series of tests concerned the swelling pressure of the clay. An indication of this pressure can be obtained by placing three or four specimens, cut from an undisturbed sample, in oedometers under different pressures and observing the resulting movement. The average of five such tests showed that with pressures of less than about 1·2 ton per square foot the specimens swelled, and that with higher pressures they consolidated. This value was, therefore, taken as indicative of the swelling pressure of the clay, although it actually measures the capillary pressure in the samples.

In the second series the volumetric shrinkage of the clay, on being allowed to dry, was measured. A mercury displacement apparatus was used, and five specimens were tested. There was little variation in the shrinkage limit, the mean value of which was 18 per cent. It was observed that air commenced to enter the specimen at a water-content of about 23 per cent. Shrinkage tests on remoulded clay gave an average shrinkage limit of 15 per cent.

Finally, the specific gravity of the particles of the clay was determined on dried and powdered material. The standard pycnometer method was employed, the fluid used being kerosene. The mean value was 2·74, with a range from 2·71 to 2·78 : forty-two samples were tested.

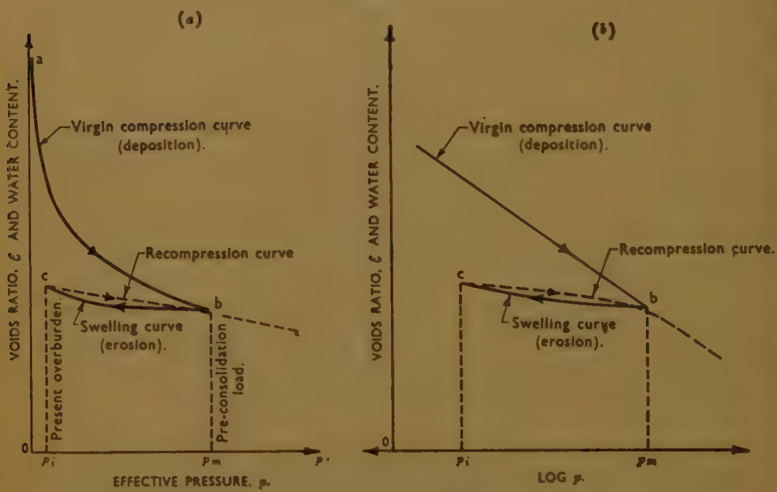
Tests to Estimate the "Pre-consolidation" Pressure of London Clay.

The London Clay was brought down in the form of mud by a large river flowing in Eocene times, and this mud was deposited under estuarine and marine conditions[16]. In the region from which the samples were obtained the clay was not covered by the Quaternary ice-sheet, but in the course of its history it has been subjected to the weight of overlying sediments some hundreds of feet thick. The maximum pressure arising from the weight of these overlying sediments is known as the "pre-consolidation" pressure ; in the case of London Clay it has been of such a magnitude as to consolidate the mud into the compact clay now found. The overlying sediments and a considerable thickness of the clay itself have since been eroded, but this has probably not decreased its compactness to any important extent.

The influence of this load sequence on an element of London Clay situated at a depth of about 35 feet below river-bed-level can be illustrated in a very simplified manner by the results of an oedometer test carried out on a sample of clay remoulded with water to form a slurry. The slurry represented at point a in *Figs. 14* corresponds to the state of the

element under consideration, when it was being deposited as mud. The deposition of successive sediments is represented by increasing the pressure in the oedometer, and the voids-ratio of the clay decreases along what is known as the "virgin compression curve." The deposition continued until an uplift of the sea-bed resulted in the formation of dry land; the corresponding state of the clay is shown at point b. The new land surface was then eroded; this process is represented in the test by reducing the pressure, when the clay expands slightly and finally reaches the point c, which corresponds to the present overburden of the element, a pressure of about 1 ton per square foot.

Figs. 14.



PRESSURE-VOIDS RATIO CURVES FOR SLURRIED CLAY, SIMULATING LOAD HISTORY OF NATURAL CLAY.

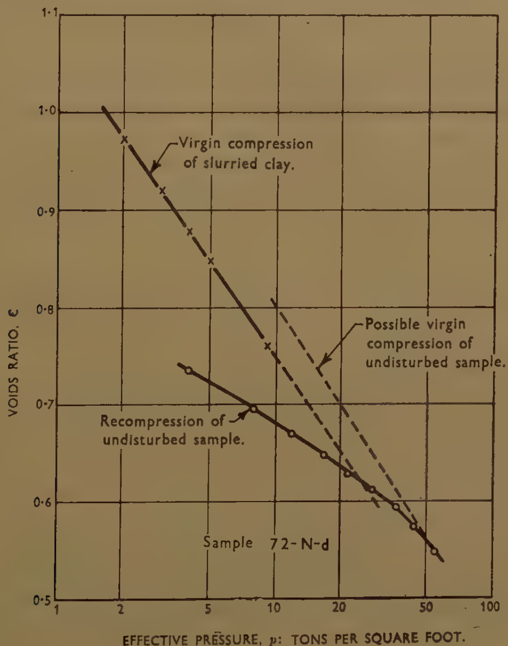
An attempt was made to determine experimentally the pre-consolidation pressure of London Clay by the method suggested by Casagrande [17]. This method is based upon the observation that if the sample in the oedometer at point c is subjected to increase in pressure, the recompression curve passes very close to point b and then proceeds along the "virgin compression curve" as if no unloading and reloading had taken place. The change from recompression to "virgin compression" is clearly seen if the voids ratio is plotted against the logarithm of pressure, as shown in *Figs. 14* (*b*). Consequently, if an undisturbed sample of clay is obtained and recompressed in the oedometer, point b should be revealed. Using this method, Casagrande obtained a value for the pre-consolidation pressure of the Laurentian clay (Canada) of about 8 tons per square foot; this value could be confirmed from geological evidence. A similar con-

firmation has recently been obtained by Mr. I. B. Crosby [18] for a Triassic shale with a preconsolidation pressure of about 70 tons per square foot.

The results for an undisturbed sample of London Clay are shown in *Fig. 15*, which indicates that a decided change of slope occurs at about 35 tons per square foot. Unfortunately the apparatus available was limited to a pressure of 55 tons per square foot and the evidence is not conclusive, as the existence of the "virgin" curve could not be proved.

The lowest possible value of the pre-consolidation pressure can, however, be obtained with some degree of certainty by the intersection of the

Fig. 15.



recompression curve of the undisturbed sample and the "virgin" curve of a slurried sample of the same clay. This will give the lowest value, because it is known that under any given pressure the voids-ratio of a slurried sample is lower than that of an undisturbed sample, with its more complex structural arrangement of particles. In *Fig. 15* the value given by this method is 26 tons per square foot; a similar test on another sample gave 21 tons per square foot.

From the thickness of the London Clay and of the sediments known to have been deposited over it (principally the Bagshot Series), it is estimated that the pre-consolidation pressure is very approximately 20–30 tons per square foot. Although a more accurate estimate may be possible, this

estimate is sufficiently close to enable the correctness of the order of the experimental values to be checked.

Finally it may be mentioned that the earth movements which resulted in the uplift of the sea-bed also caused a folding of the strata of the London Basin, and it is possible that the fissured nature of the clay is due to the shearing stresses set up by this action.

Summary.

A laboratory examination was made of a comparatively large number of disturbed and undisturbed samples of London Clay taken over a fairly extensive site in the region between 40 feet and 90 feet above the bottom of the stratum.

The clay is of the stiff fissured type and experiments as well as geological estimates indicated that it had been pre-consolidated under a pressure of at least 20 tons per square foot.

The clay was found to exhibit variations over the site; the mean value and the total range of values of the more important properties are given in Table VII.

TABLE VII.

Property.	Mean value.	Total range.
Natural water-content: per cent. of dry weight	26·6	22·6–31·8
Liquid limit: per cent. of dry weight	76·6	60–96
Plastic limit: per cent. of dry weight	26·6	21·4–32·4
Specific gravity of particles	2·74	2·71–2·78
Compressibility: square feet per ton	93×10^{-4}	$63–120 \times 10^{-4}$
Coefficient of consolidation: square inches per minute	$8·5 \times 10^{-4}$	$6·4–11·7 \times 10^{-4}$
Shear strength under zero pressure: lb. per square foot	780	580–1,100
Shear strength under 1 ton per square foot: lb. per square foot	2,100	1,600–2,600
Unconfined compression strength: lb. per square foot	6,600	2,000–10,000

It was found that the values of the mechanical properties could be correlated with the index properties of the various samples, the compressibility and shear strength being related to the liquidity-index and the coefficient of consolidation to the liquid limit.

The index properties were determined on a total of 104 samples, and the variations in these properties were examined in detail over the depths of the boreholes and also over the depth of single undisturbed samples. This examination showed firstly that the index properties vary over a distance of a few inches by an amount, the maximum value of which equals one-third of the total range, and secondly that, in each of the boreholes, this variation is not exceeded over zones of many feet in thickness.

The horizontal variations were found to be slight. All the boreholes showed a silty zone, although this varied to some extent in both level and thickness.

Tests on samples of London Clay from a few other sites at widely separated points in the London area gave results which were within the range quoted in Table VII.

ACKNOWLEDGEMENTS.

The work described was carried out at the Building Research Station of the Department of Scientific and Industrial Research, partly in the course of an investigation for Messrs. Rendel, Palmer and Tritton, consulting engineers, on behalf of the London County Council, and partly in the course of work undertaken in conjunction with the Committee of The Institution of Civil Engineers on Earth Pressures. The results are published by permission of the Director of Building Research.

Acknowledgement is also made to Mr. R. V. Allin, M. Inst. C.E., for his very helpful collaboration on the site.

The Paper is accompanied by fourteen sheets of drawings, from which the Figures in the text have been prepared.

APPENDIX.

BIBLIOGRAPHY.

(1) K. von Terzaghi. "Stability of Slopes of Natural Clay." Proc. Harvard Conf. on Soil Mechanics, 1936, Vol. I, Paper G–7.

(2) S. Buchan. "The Water-Supply of the County of London from Underground Sources." Memoir of the Geological Survey, 1938, H.M. Stationery Office. Pp. 129–136.

(3) Report of the Building Research Board for the Year 1937. H.M. Stationery Office. P. 95.

(4) M. J. Hvorslev. "The Present Status of the Art of Obtaining Undisturbed Samples of Soils." Supplement to Proc. Purdue. Conf. on Soil Mechanics 1940, p. 20.

(5) R. B. Peck. "Sampling Methods and Laboratory Tests for Chicago Subway Soils." Proc. Purdue. Conf. on Soil Mechanics, 1940, p. 140.

(6) A. Casagrande. "Research on the Atterberg Limits of Soils. *Public Roads*, Vol. 13 (1932), No. 8, p. 121 (October, 1932).

(7) K. von Terzaghi. "Sampling, Testing and Averaging." Proc. Purdue. Conf. on Soil Mechanics, 1940, p. 151.

(8) "Recent Marine Sediments." A Symposium published by the Amer. Assoc. Pet. Geologists, 1939, pp. 273 and 441.

(9) A. W. Skempton. "Settlement Analysis of Engineering Structures." *Engineering*, Vol. 146 (1938), p. 403 (30 Sept., 1938).

(10) L. F. Cooling and A. W. Skempton. "Some Experiments on the Consolidation of Clay." Journal Inst. C.E., Vol. 16 (1940–41), p. 381 (June 1941).
(11) D. W. Taylor and W. Merchant. "A Theory of Clay Consolidation Accounting for Secondary Compression." J. Math. and Phys., Vol. 19 (1940) No. 3, p. 167 (July 1940).
(12) A. Casagrande and R. E. Fadum. "Notes on Soil Testing for Engineering Purposes." Harvard Graduate School of Engineering. Publication No. 268, p. 48 (January 1940).
(13) K. von Terzaghi. Proc. Harvard Conf. on Soil Mechanics, 1936, Vol. III, Paper J–8.
(14) G. Ellson and L. F. Cooling. Discussion on "Cliff Stabilization Works in London Clay." Journal Inst. C.E., Vol. 14 (1939–40), pp. 428 and 432 (October 1940).
(15) L. F. Cooling and H. Q. Golder. "A Portable Apparatus for Compression Tests on Clay Soils." *Engineering*, Vol. 149 (1940), p. 57 (19 Jan., 1940).
(16) H. B. Woodward and C. E. N. Bromehead. "The Geology of the London District." Memoir of the Geological Survey, 1922, p. 27, H.M. Stationery Office.
(17) A. Casagrande. "The Structure of Clay and Its Importance in Foundation Engineering." Journal Boston Soc. C.E., Vol. 19 (1932), p. 168 (April 1932).
(18) I. B. Crosby. "Engineering Geology Problems at Conchas Dam, New Mexico." Proc. Am. Soc. C.E., Vol. 65 (1939) No. 1, p. 29 (Jan., 1939).

Paper No. 5273.

"The Burma–Yunnan Road."

By John Francis Hunter Nicolson, M.C., Assoc. M. Inst. C.E.

(*Ordered by the Council to be printed with written discussion*[1].)

TABLE OF CONTENTS.

Introduction.

In view of the importance which the Burma–Yunnan Road has now assumed and the publicity it has received recently, a Paper on the subject recounting the engineering and other aspects may be of interest.

The index map (Fig. 1, Plate 1) shows the chief inland communications in China, and is intended to give an impression of the vastness of the

[1] Correspondence on this Paper can be accepted until the 15th April 1942, and will be published in the Institution Journal for October 1942.—Sec. Inst. C.E.

country, and the relation of the Burma road to the whole outline. Before the opening of the Burma road the main outlets from Yunnan were down the rivers to the seaports of China, along the railway from Kunming to Indo-China, and along the system of roads which have been constructed under the new regime during recent years. Communication with Burma was restricted to pack and coolie transport along various caravan routes. Soon after the invasion by Japanese forces, the central Government of China realized that other lines of communication with the outer world would be necessary for the unoccupied part of the country, which was converging on Yunnan, and it was decided to develop these from Kunming to Burma. The opening of a highway appears to have received the first efforts, and the construction of a railway along a different route has also been taken up.

Construction of the Road.

The motor road construction was commenced about the end of 1937, and in February 1938 the Burma Government considered the provision of road connexions to the border from the nearest railhead at Lashio and from the Irrawaddy waterway at Bhamo. Lashio lies in the Federated Shan States—a collection of small States largely self-administered directly under the Governor of Burma and politically separated from Burma proper—and is the administrative headquarters of the Northern Group. The point at which the route crosses the border is also in the Northern Shan States, so that the whole of the Lashio connexion and part of the road to Bhamo, which lies in Burma proper, come under the jurisdiction of the Federated Shan States.

Practically the whole countryside in the Shan States and Yunnan is hilly and mountainous, flat parts being confined to small valley plains. The route traversed in Yunnan is intersected by two large rivers, the Salween and the Mekong. Fig. 2, Plate 1, is a profile of the road, the Yunnan section of which was plotted from rough notes made in the course of a journey by car: it shows the extent to which the road climbs up and down through passes in the hills and gorges in the valleys, with occasional stretches across paddy plains and over high rolling plateaux.

The Shan States section of the Lashio connexion is 114 miles in length and presents few difficulties in road construction. It includes a number of small hill sections and one of moderately stiff gradient between Hsenwi and Kutkai; the remainder lies mainly in undulating highland.

The distance from the border to Bhamo is 45 miles, 11½ miles of which is common to both routes; thereafter the road descends into the Shweli river valley, which it follows for about 20 miles before crossing the river and then, after crossing the Burma border, ascends into a difficult stretch of the Kachin hill tracts of the Bhamo District.

From the border into Yunnan the road rejoins the Shweli valley for a

short distance and then ascends through the Chefang, Mangshih, and Lungling plains, with intervening hill sections until it crosses the pass leading to the Salween gorge. It then crosses the huge divide to the Mekong, and climbs a further two ranges before reaching the large town of Hsiakuan, which lies at the south end of the Talifu lake. A glance at a map of China will indicate that over the remainder of the road onwards to Kunming similar difficulties are encountered.

Apart from the almost continuous troubles experienced in cutting a tortuous road along steep hillsides, many lengths of which are rocky, serious difficulty was caused in places by unstable material, owing to blockage in the rainy season by landslides falling on the road, and to loss of formation-width through slips below the road. One particular length of this nature is on the hill section between Mangshih and Lungling; in places the soil is very unstable, whilst a treacherous type of decomposed granite is washed down in large quantities with any small concentration of surface water. The experiences of two rains seasons, during which many traffic delays occurred, resulted in the construction of a deviation for a length of 5 miles to a location where better soil was found.

The Chinese authorities set themselves the task of opening this road in the one working season of 1937–1938. The seasons are similar to those in the Shan States—a rainy season lasting from June to October and the rest of the year comparatively dry, with cold weather from November to February. In the rains all labourers return to their villages to cultivate their fields, and much malaria is contracted in the valleys. Labour for road work appears in November and December; as large tracts of the country are thickly populated, it is plentiful, although difficulties arise in areas where population is scarce. From Kunming to Hsiakuan a very rough motor road existed, which had to be improved and resurfaced. An entirely new and surfaced road had to be constructed from Hsiakuan to Mangshih, a distance of about 281 miles. From Mangshih to the border, 51 miles, a narrow and badly-alined road, usable by motor vehicles in dry weather, had to be widened, re-alined in parts, and surfaced. The task was too great, especially as the rains broke unusually early, but an enormous quantity of work was done, including the formation—though probably not up to the width intended in many places—and a good deal of very rough surfacing. The standards of construction were as follows:—

Traffic: Heavy lorries carrying up to 5 tons may be used.

Formation width: 7 metres (23 feet) in hill section and 8 metres (30 feet) in the plains.

Maximum gradient: 1 in 12½.

Minimum radius of curves: 15 metres (50 feet).

Surfacing: 30 centimetres (12 inches) thick over bad soil, 20 centimetres (8 inches) over ordinary soil, and 10 centimetres (4 inches) over good soil. 17-centimetre (7-inch) stones will be used for soling and 8-centimetre (3-inch) and 5-centimetre

(2-inch) stones for surfacing. No mechanical rollers will be used for consolidation. River gravel will be used where stone is not available.

Bridges will be constructed of dressed jungle wood, in some cases with stone abutments.

Suspension bridges to carry laden vehicles weighing $7\frac{1}{2}$ tons.

Culverts will be of jungle wood.

In the next season work was continued on widening the formation, making diversions where necessary, surfacing, and constructing permanent culverts and bridges. The main reason for traffic stoppages had been poor drainage, whilst far too few culverts had been made, and catchwater and side drains were lacking. Many of the temporary timber bridges also gave trouble and a large effort was necessary to get all of them completed, as they consisted of stone masonry, arched in some instances and carrying timber decking in others. By the rains of 1939 much of this work had been completed, but the difficulties were so great that there were considerable traffic delays owing to landslides, washouts, and failure of the surfacing in places. A small quantity of plant was acquired to expedite and improve matters, including motor road-rollers, portable compressors for rock drilling, dumpers, etc.

The 1939–1940 season was spent in improving the surfacing, including superelevating curves, further widening, regrading and re-alining curves, and completing culverts and bridges. Reports indicate that the road has been open throughout the 1940 rains, and that travelling conditions are fairly good. So far as is known no bitumenizing has been done, and the surface is maintained by applying thin coats and patches of stone broken to small gauge, and blinding, watering, and consolidating where rollers are available.

Federated Shan States Section.

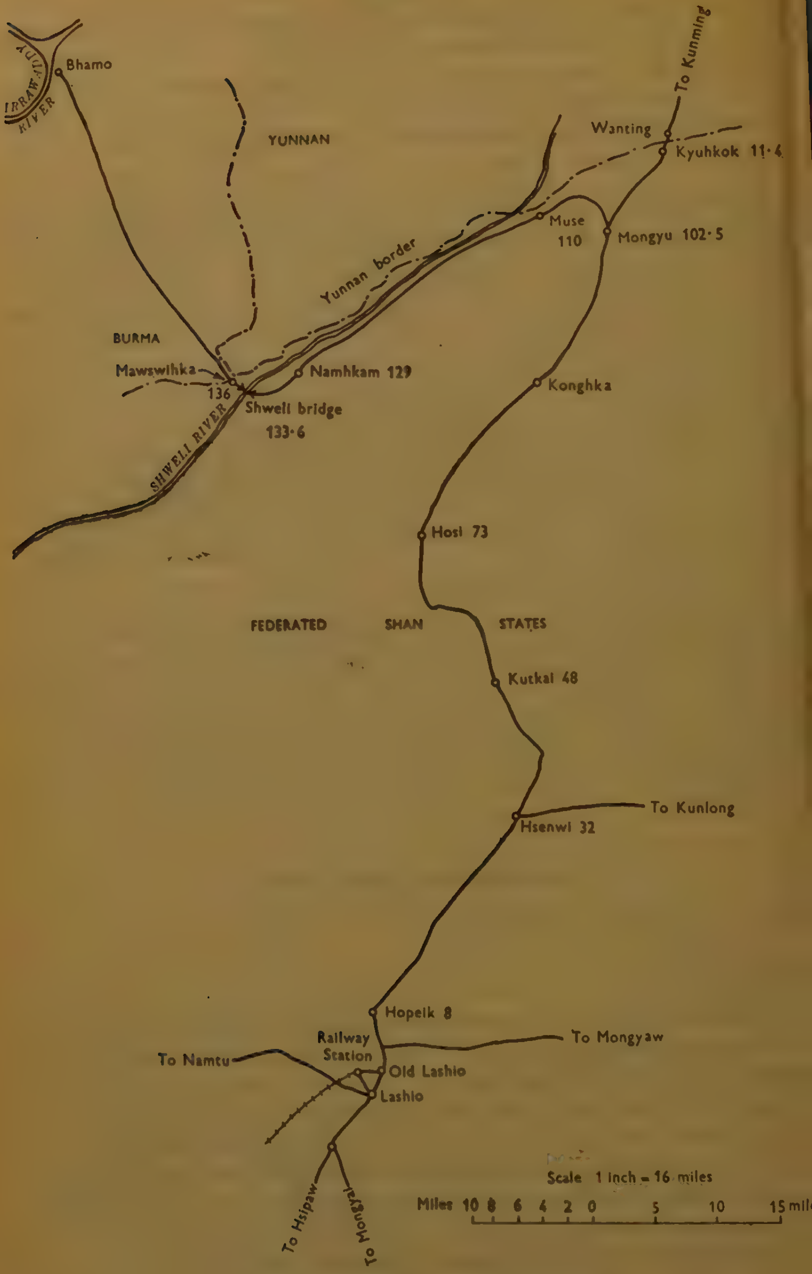
Fig. 3 is a map of the locality.

Lashio Connexion.

At the inception of this project an all-weather road existed from Lashio to Kutkai (mile 48), most of the length being gravelled and the rest metalled, and partly bitumen-painted. From Kutkai to Hosi (mile 73) the road had been lightly gravelled, but was not fit for traffic in heavy rainy weather; onwards to the border (mile 114) it was unsurfaced. The formation was narrow, the alinement was poor, culverts were lacking, a number of timber bridges required replacing, and two major bridges required strengthening.

The decision to undertake extensive improvements was not made until March 1938, when the working season was nearly at an end; but a big

Fig. 3.



Federated Shan States Section.

effort was made to make the road passable for the rains in the anticipation that the Chinese might, contrary to expectation, do likewise over the border. Unfortunately, unusually early rain intervened throughout May, completely upsetting the program which had been planned and causing appalling traffic conditions for the rest of the rainy season. Very few vehicles got through and contractors' lorries carrying surfacing materials had a rough time; nevertheless the work was pushed on with local labour, which was unaccustomed to the type of work, and under very unfavourable conditions. For these reasons much unnecessary expenditure was incurred.

The 1938–1939 season was spent in completing the general improvements and providing rough but secure surfacing, which, with some trouble in a few stretches, was able to carry all the traffic without any delays during the rains of 1939.

In July 1939, when the importance of the road began to be more fully realized, the Government decided that further improvements were necessary, and a program was prepared for metalling and surfacing with bitumen throughout; this work was stated in the 1939–1940 season, and is now nearing completion.

Various factors bore upon the program of work. First, the whole cost of the work was to be borne by the Federated Shan States, which had, at the same time, to execute a considerable program of road construction, improvements, and repairs; in fact, the outlay on this project was to absorb nearly half the funds that were available for all other road development during the 3 years when work was in full swing. Therefore, funds were severely limited, and costs had to be kept in mind all the time, as well as urgency. Owing to this lack of ample funds not only had the specification of work to be restricted to the bare minimum, but also the supervisory staff and the plant had to be on a very modest scale. Then there was the possibility that the Chinese efforts might not materialize, either in the provision of their road, or of the motor vehicles to carry the traffic, and that provided another incentive to the restriction of expenditure and emphasized the necessity for proceeding from stage to stage in the light of events as they happened and as best they could be foreseen. The main fortunate factor on this work was that, for the working season, a large force of labour comes in from Yunnan about December, to do road work until April. They are hard workers and very suitable for the type of work required. Normally, more of these coolies than are required come over to the Northern Shan States, but latterly some restriction and shortage have been caused by the requirements of the authorities in Yunnan.

As stated on p. 278, *ante*, the Chinese were preparing for motor vehicles with a carrying capacity of up to 5 tons, and the major bridges were designed to carry laden vehicles of up to $7\frac{1}{2}$ tons. It was quickly realized that on such a severe hill road the most suitable type of truck for transport would be comparatively small. During the first year or so, trucks of 2 tons

carrying capacity were used almost entirely on the Federated Shan States section, and the laden weight was restricted to 4½ tons. The Chinese transportation authorities then began to import large numbers of new vehicles to carry 3 tons, and also a few of larger capacity, believed to be only in transit for other work. The traffic to be catered for was therefore assumed to be large numbers of 3-ton trucks weighing, laden, 5½–6 tons, and the restriction has been amended accordingly. Larger vehicles up to a laden weight of 8 tons, are allowed on special permits.

Improvements.

Improvements have taken place in two main stages. The first comprised:—

(i) *Realinement.* Owing to the urgency of the need for all-weather traffic, and the necessity for low cost, realining on a large scale could not be undertaken. A considerable number of small diversions to ease curves and gradients and to improve visibility were, however, made. An entirely new road, 11·4 miles long, was opened from the border to meet the Lashio–Bhamo road at Mongyu (mile 102·5) as the old alinement was unsuitable.

(ii) *Formation.* A 24-foot width was decided on as it was anticipated that traffic might develop to the extent of requiring two separate lanes, and this width was considered to be minimum for the purpose in open road. For expensive side-cutting on hill sections, a minimum of 18 feet was considered sufficient, as traffic would be slower and driven with more caution. Typical cross-sections are shown in Fig. 4, Plate 1.

(iii) *Surfacing.* Throughout the length of the road limestone is available, mostly within a short distance, in the form of fairly hard stone or in its decomposed state as angular graded gravel (*badjri*), which, when a small percentage of clay is present, can be bound and stabilized into an excellent road surfacing material. Many miles of roads in the Shan States are composed of a layer of this gravel, spread on a sectioned earth bed, and left to be consolidated by the traffic. They carry throughout the year a moderate amount of mixed cart and motor traffic, without serious trouble except where the soil lacks the required clay content and becomes corrugated and dusty, but they require a season and some maintenance, to settle down. In the case of the Burma–Yunnan road the volume and kind of traffic was an unknown quantity, and it was considered that a higher-grade specification was necessary. A water-bound and bitumen-painted macadam road was out of the question at that stage, owing to the cost, the length of time required for construction, and the fear that it might not be justified by the volume of traffic. The alternative, which was adopted, was to lay, hand-packed, a 4½-inch layer of soling stone on the sectioned road bed, spreading and, if possible, rolling a layer of gravel underneath to stabilize the soil where it was poor, or on new filling. This

foundation was blinded with earth and gravel and consolidated later by a 6-ton or 8-ton roller. It then had a layer of gravel spread over it, and the surface was maintained simply by further applications of gravel and occasional dressing by coolies. The drawbacks were that, with the comparatively hard stone foundation, the gravel tended to pulverize and be washed or carried off as dust, exposing the rough stone surface of the soling, and that, with fairly fast and heavy lorry traffic, corrugating was very prevalent. It certainly was, however, a very cheap surface to construct and was not unduly expensive to maintain, as the gravel only costs 3 to 4 *rupees* per cubic foot spread on the road. Other advantages were that the process was quick and easy, and required no plant except a few rollers; but the most important advantage was that it enabled a uniform foundation, throughout the varying conditions of the road, to be obtained at the minimum cost, by simply adding additional courses of soling stone of a thickness depending upon the defects exposed; thereby ensuring that the subsequent and more expensive surface treatment would be done in the most economical manner. This type of surfacing was laid to a width of 10 feet, except where the road was already metalled; and as considerable traffic was anticipated, the berms were gravelled to a width of 3 feet on each side to allow vehicles to pass at a low speed with comparative safety. The approximate cost of this surfacing was 2,750 *rupees* per mile.

(iv) *Minor Bridges.*

The culverts and minor bridges were of the types common in the Shan States. Culverts were of dry-stone, the larger ones having reinforced-concrete slabs, and were of the full formation width of 24 feet between parapet walls. Minor bridges were mostly of stone masonry sub-structure with decking of reinforced-concrete slabs on rolled steel girders, providing a roadway of 10 feet between wheel-guards. The widening of these bridges to 20 feet for two lanes of traffic was considered, but was not proceeded with.

(v) *Major Bridges.*

An old, unstiffened suspension bridge over the Namtu near Hsenwi, capable of carrying a 6-ton roller, was replaced by a steel truss designed to carry a single vehicle of 8 tons laden weight, or a line of vehicles each weighing, laden, 4 tons. The roadway was 10 feet wide between wheel-guards and the flooring was of timber.

The actual costs of the above-mentioned works were about 583,000 *rupees* for items (i) to (iv) and 34,000 *rupees* for the Namtu bridge at Hsenwi.

The second stage of improvements comprised :—

Surfacing.—As traffic developed in intensity the soling stone and gravel

strip 10 feet wide gave too rough a surface, whilst, in certain sections, the 4½-inch thickness of stone was inadequate and the gravelled berms were insufficiently stable. It was therefore decided to provide a bitumenized surface on the 10-foot strip, and to make the 3-foot berms on each side uniformly suitable for dealing with passing traffic. This entailed the thickening of the soling stone in the sections where it had become rutted, pot-holed, or sunk in patches, the rectifying of minor faults in grading and alinement, superelevating at corners, and the laying of soling stone on the berms where gravel was unsatisfactory. Wherever soling-stone thickening, rectifying, or laying on berms was done, reblinding with earth and gravel was necessary. It was finally decided that to provide a surface suitable for bitumenizing, a 4½-inch course of water-bound macadam would be suitable, bearing in mind that the surface of the soling was almost invariably rather rutted, and was not true to camber or longitudinal section; and that there was a carpet of gravel mixed with soil over the soling, which would have to be scarified and raked to provide a layer of hoggin to work up into the stone metal under consolidation. Another method considered for providing an improved single-way traffic lane was to construct a pair of concrete or bitumenized strips in the wheel-tracks: this was studied in some detail. The Author's report on the subject, as prepared at the time, is given in Appendix I. In the construction of this 10-foot strip of bitumenized macadam certain difficulties had to be faced. Obviously it was necessary to do the work quickly because of the increasing traffic. The collection of most of the stone metal was planned to be done in one working season, 1939–1940, advantage being taken of the seasonal labour to obtain it cheaply and quickly, thus avoiding the purchase of stone-breaking machinery, which would have been of little use after completion of the project. In order that the quantity of material lying at the roadside should be kept as small as possible, to avoid interference with traffic, and loss, it was necessary to devise the best possible method of laying and consolidating it throughout the dry season, instead of holding it all over until the rains broke and provided the customary suitable conditions for water-bound work. The adoption of this dry-weather consolidation specification presented also the advantage that the number of rollers required to complete the work by early 1941 could be reduced; but it was realized that the results might not be so satisfactory. A considerable amount of time and trouble was therefore devoted to devising the best method to adopt, which may be summarized as follows. The gravel and earth surfacing was raked up to form an even coat of hoggin of the required thickness, on to which the metal was spread. Water-carts were employed considerably in excess of monsoon requirements, and the metal was given a good watering to enable the rolling to bring the hoggin well into the metal. When the metal was well consolidated and showed little movement under the roller, gravel blindage was applied in successive light applications, watered from kerosene-tins with perforated bottoms

to carry it into the interstices, with occasional rolling during the process. The intention was to ensure that the voids in the whole thickness of metal after consolidation were as completely packed as possible; and this was found to be by no means an easy operation. When it had been completed, the surface was opened to traffic for a few days to allow the pneumatic tires to work in the blindage further in defective places; but care had to be observed that bitumenizing was not delayed too long, as unravelling was unavoidable. The bitumenizing required much thought, owing to the variety of materials and specifications available. The first decision was to use an imported straight bitumen which required heating to 375° F. and to apply it at the rate of about 45 lb. per square foot with stone chips, or screened hard gravel. This process was abandoned for the following reasons:—much of the metal, being the rather soft limestone used for soling, was not up to the standard desirable for water-bound macadam; in fact in a few places it was definitely poor. Possibly a better quality could have been obtained, but that would have entailed much greater expense, and additional time for collection. In any case, it was decided to make do with the best that could be supplied at the low rates tendered, and it was therefore considered that, in place of the normal rather heavy bitumen carpet bound to the surface of the metal, resulting from a coat of hot bitumen, which seals over deficiencies in the consolidation, an application of a cut-back bitumen, which would penetrate into the blindage and considerably assist in supporting and preventing wear to the top layer of metal, would be of the greatest benefit. The cut-back selected has a bitumen-content of about 80 per cent. and had been experimented with in the Shan States in various ways. Its analysis is given in Appendix II. It was known that, when this cut-back was applied to the damp surface of a typical gravelled road, which had been watered and rolled up to camber, at the rate of 30 lb. per square foot, a surface was obtained which would withstand a large volume of 2-ton lorry traffic in any weather. This quite small quantity of cut-back, after blinding with gravel, and rolling, gave a bitumenized thickness of $\frac{3}{4}$ inch to 1 inch, indicating that penetration was considerable. A short length of work of this nature had, in fact, been tried in Kutkai Town, and was standing up well to the Yunnan-road traffic; but it was thought that the specification might hardly fulfil the requirements on a large scale. Various methods of applying the cut-back to the metalled surface were tried. For dry-weather consolidation, when the texture of the surface was inevitably a little open owing to lack of really plentiful watering, an application from perforated kerosene cans of 35 lb. per square foot on to a dampened and brushed surface gave an ample and fully covered carpet, which was blinded with screened gravel of $\frac{3}{8}$-inch to $\frac{3}{4}$-inch gauge and rolled. The spreading of the blindage was deferred, in order to obtain better penetration when circumstances permitted, but this was rare. The moistening of the surface facilitates spreading of the cut-back, and assists in penetration.

During the rains, when the consolidated surface could be allowed to wait for a few weeks, if kept blinded with gravel, the texture became really dense, and an application, in the same way, of only 22 lb. per square foot, was found to be adequate. Other advantages of this cut-back are that the cost of application is much lower than that of hot bitumen, the saving counterbalancing the higher initial cost of the material; it is extremely easy to apply, and the quantity can be varied at will. Additional coats or patches can be applied with little trouble, when necessary, thus ensuring that the surface is properly sealed and built up in thin layers, rather than in heavy applications which are liable to form puddles and rich patches. It appears to be equally as suitable for seal coats as for the first coat, and, so long as the sealing process is going on and penetration is desirable, is better than a hot material. Its power of penetration obviates the necessity for thorough brushing and dusting of the surface. It can be used at selected dry intervals in monsoon weather—an important advantage on this road. The heavy traffic would, undoubtedly, have unravelled consolidation after a few months, whilst the re-preparation of the surface would have been expensive and unsatisfactory, and would have required more bitumen. The cost of this surfacing, including 4½ inches of water-bound macadam treated with a first and a seal coat of cut-back, and bringing the berms up to proper section 3 feet wide each side with gravel or stone topping amounts to approximately 5,250 *rupees* per mile, allowing an average carriage of 60 miles for the cut-back from railhead.

The suspension bridge at Namhkai, of 185 feet span, was very narrow and insufficiently stiffened. A steel stiffening girder was used to replace the wooden one, thus enabling the width to be increased to 8 feet 6 inches between wheel-guards, and the carrying capacity to a line of laden lorries, each weighing 4 tons, or a single vehicle weighing 8 tons.

The estimated cost of these improvements amounts to 610,500 *rupees* for surfacing and 17,000 *rupees* for the Namhkai bridge, and it is not anticipated that there will be much deviation from this estimate.

On the whole the results have been satisfactory to date. The conversion of a road, in haste, at one operation from rough slow-travelling conditions to a bitumenized surface, upon which maximum vehicle-speeds were expected, has revealed many places where longitudinal grading, curves, and superelevation have not received the attention which would have been possible if development had been more gradual or more time had been available for survey. The consolidation had to be effected under considerable traffic, and consequently, in places is not so good as it might have been; but actual foundation failure, needing an additional coat of metal, has occurred in only a few short sections. The bitumenized surface is also rather variable, largely because of faulty consolidation; whilst supplies of the cut-back were not so regular as was desirable, and some unnecessary deterioration occurred. The gravelling and, in places, the soling of the berms has, on the whole, been satisfactory, although owing

to the interference to traffic, caused by the accumulation of materials at the roadside, and by the consolidation work, it is, perhaps, rather early to judge their performance. Average daily traffic figures are given in Appendix III. As little effort at regulation has been made, the number of vehicles is considerable. If a further increase occurs, a two-lane carriageway will have to be contemplated, by increasing the bitumenized width to 18 feet or 20 feet. The fact that the berms have already been stabilized will make this considerably less expensive.

Expenditure has amounted to 345,000 *rupees* in 1938–1939 and 498,000 *rupees* in 1939–1940; and it was expected to be about 366,000 *rupees* in 1940–1941.

The Bhamo Connexion.

The position in March 1938, when the whole matter was being reviewed at the beginning, was that from Mongyu, the junction of the Lashio–Bhamo road where the branch takes off for the Yunnan border, to the Shweli bridge, near the Burma border, there was a badly alined and practically unsurfaced road, which was opened for dry-weather traffic by constructing, annually, a large number of bamboo minor bridges and culverts and a bamboo bridge about 150 feet in length over a large stream, and dressing up the surface. The Burma Government were nearing the completion of the construction of a suspension bridge of 400 feet span over the Shweli river, to carry 10-ton vehicles, and were maintaining the section of road from that bridge to the Mawswihka, although that short length was in the Shan States. From the border into Bhamo, a distance of 65 miles, a narrow and only partially-surfaced hill-road existed through very broken jungly country, where the conditions were difficult. It was estimated that to make this Burma section into an all-weather road to carry fairly heavy traffic, considerable expense and time would be entailed; and it was mainly for this reason that it was decided rather to concentrate efforts on the Lashio connexion. As, however, a certain volume of traffic, mainly in the dry season, was anticipated on the Bhamo connexion, it was decided to start work on improvements to the Shan States section.

Standards of construction similar to those on the first stage of improvements of the Lashio connexion were decided upon; and in the 1938–1939 season the formation of most of the length was completed, a reinforced-concrete pile bridge was constructed over the one large stream, a number of minor permanent bridges were constructed, some pipe culverts were made, the numerous remaining waterways were bridged with jungle-wood and bamboo culverts, and the surface was lightly gravelled. These works enabled light motor traffic to use the road throughout the rains of 1939; but as the Lashio connexion entailed a very heavy drain on the resources of the Shan States, it was considered inadvisable to proceed with the full program of improvements. Further minor improvements have been

effected, and the road is now maintained as a gravelled road, suitable for light motor traffic except in excessively wet periods.

The Paper is accompanied by four sheets of drawings, from which Plate 1 and the Figure in the text have been prepared, and by the following three Appendixes.

APPENDIX I.

Report on Concrete Trackways.

1. " I have now examined more fully the relative merits of concrete strips or trackways and a 10-foot wide asphalted surface.

2. " Correspondence and notes on the subject of concrete trackways are available in the periodical magazine entitled *Indian Roads*, published by the Department of Industries and Labour, Public Works Branch, Government of India and commenced from the year 1931. There are also a number of articles on asphalt trackways in *Improved Highways*, a magazine produced by the Shell Company of South Africa, one of which articles, in Vol. 6, No. 4, of December, 1933, written by the Chief Road Engineer of Southern Rhodesia, deals with concrete trackways.

3. " With regard to India, experiments have been carried out in Assam, the Central Provinces, the Punjab, Bharatpur State, and the Delhi Province. The Assam experimental work approximated to conditions, including traffic intensity, in the Shan States; whereas in the other cases it was primarily intended in connexion with the problem of carrying heavy bullock-cart traffic, additional to other varieties. With the exception of a comparatively few miles of road which carry heavy potato traffic by bullock cart, this problem is not an important one in the Shan States, and in any case, is not the problem which is being considered now. It would appear, however, from the results of experiments so far given in *Indian Roads*, that concrete trackways are likely to prove suitable, though costly. As regards the work in Assam, as the specification was considerably cheaper than in the other cases, and appeared to be suitable for Shan States conditions, I wrote to the Chief Engineer, Assam, to obtain up-to-date information. The work was started in 1933, the tracks being 2 feet wide, 4½ inches thick and 5 feet apart at their centre-lines and the concrete un-reinforced and of a 1 : 3 : 6 mix. The berms and the space between the tracks are gravelled to protect the edges of the tracks. The design, even with minor subsequent improvements, was found too weak, however, to stand up to the traffic, which was only 100 to 150 tons a day, the main trouble experienced being the cracking of the slabs, which continued until they were covered with a bitumen carpet. This type of road is now considered to be too expensive in Assam, although in other respects it appeared to be satisfactory.

4. " The work on concrete trackways in Southern Rhodesia was similar to that in Assam, the tracks being the same width—2 feet, 4 feet 9 inches apart at their centres instead of 5 feet, the concrete 6 inches instead of 4½ inches thick and of 1 : 2½ : 5 mix instead of 1 : 3 : 6 and un-reinforced. Up to 1933 some 40 miles had been laid, and 2 years' experience indicated that the work was satisfactory. At this stage, however, concrete work was abandoned and replaced by asphalt, the reasons being, amongst others, that concrete was too costly, the process was slow, and required much semi-skilled labour and skilled supervision, and it was necessary to close long lengths of road to traffic for considerable periods while the concrete was curing.

Asphalt trackways are much cheaper, can be built much more quickly, and interference with traffic is immaterial. A program of 105 miles with asphalt trackways was then started, and in 1938 as much as 1,300 miles had been built. Traffic was of the order of 40 to 500 vehicles per day.

5. " The main conclusions to be drawn from these experiments are that for the type of traffic which now uses most roads in the Shan States, i.e. largely pneumatic-tired of medium intensity, trackways are suitable, and asphalt is probably better than concrete.

6. " The next point is to compare the three types of construction, namely concrete trackways, asphalt trackways, and a 10-foot width of asphalted road, both as regards economy and travelling conditions.

7. " The capital costs of concrete and asphalt trackways of the Southern Rhodesian type, which would suit conditions here, are estimated to be Rs. 12,000/– and Rs. 4,000/– respectively, and a 10-foot soled, metalled, and asphalted width Rs. 7,700/– per mile. The annual cost of these three types is estimated as follows :—

	Trackways.		10-foot width.
	Concrete.	Asphalt.	
Interest on Capital outlay at 3 per cent.: Rupees	360	120	231
Maintenance—			
1. Labour	125	125	75
2. Gravel	125	125	—
3. Repainting	—	150	250
	610	520	556

" Interest at 3 per cent. seems a reasonable return on outlay. The figures for maintenance labour are those found reasonable for the type of work here, after some years of experience. Provision for gravel is for the supply and spreading of the necessary quantity to maintain a 10-foot width of roadway under the effects of traffic and weather. No provision is made for repairs to the concrete, as it is possible that the amount would be very small and it would be difficult to estimate. The amounts allowed for repairs to the asphalt are on the basis that, in the long run, repainting would have to be done every fourth year for a 10-foot width and every third year for the trackways.

8. " It will be noted that the concrete trackways are considerably the most expensive, even after making no provision for repairs to the concrete, largely because of the high interest charge on outlay. The difference between the costs of asphalt trackways and 10-foot width is quite small, and is explained by the higher interest on outlay and cost of repainting the 10-foot width, being counterbalanced by lower and gravel maintenance costs.

9. " As regards travelling conditions, there is little difference, of course, between concrete and asphalt trackways except, I believe, that the joint between the edge of the trackway and the gravel would not give rise to such trouble with asphalt, as there might be some transition between the materials, whereas, with concrete there would be entire cleavage. Asphalted macadam remains flexible, and any deficiencies due to trouble in the road-bed could be more easily repaired by patching or thickening, than with concrete. A 10-foot width of asphalt is, however, undoubtedly preferable to any form of trackway, as it is practically dustless and much pleasanter to drive on.

10. " My conclusions are, then, that an asphalted 10-foot width is well worth the

small additional cost, and justified for a road of any importance. Asphalt trackways are suitable for less important roads, where cost is important, and concrete strips are only justified when heavy cart traffic is to be carried."

(Signed) J. F. H. Nicolson,
Chief Public Works Officer,
Federated Shan States.

Taunggyi,
Dated the 29th Mar., 1940.

Notes in view of developments which have taken place subsequent to the writing of the above memorandum.

The comparison made was between trackways and a 10-foot asphalted strip for a low cost single-lane carriageway. There are probably a number of other alternatives, which might be devised, but certain types which have been tried may be worth bringing to notice.

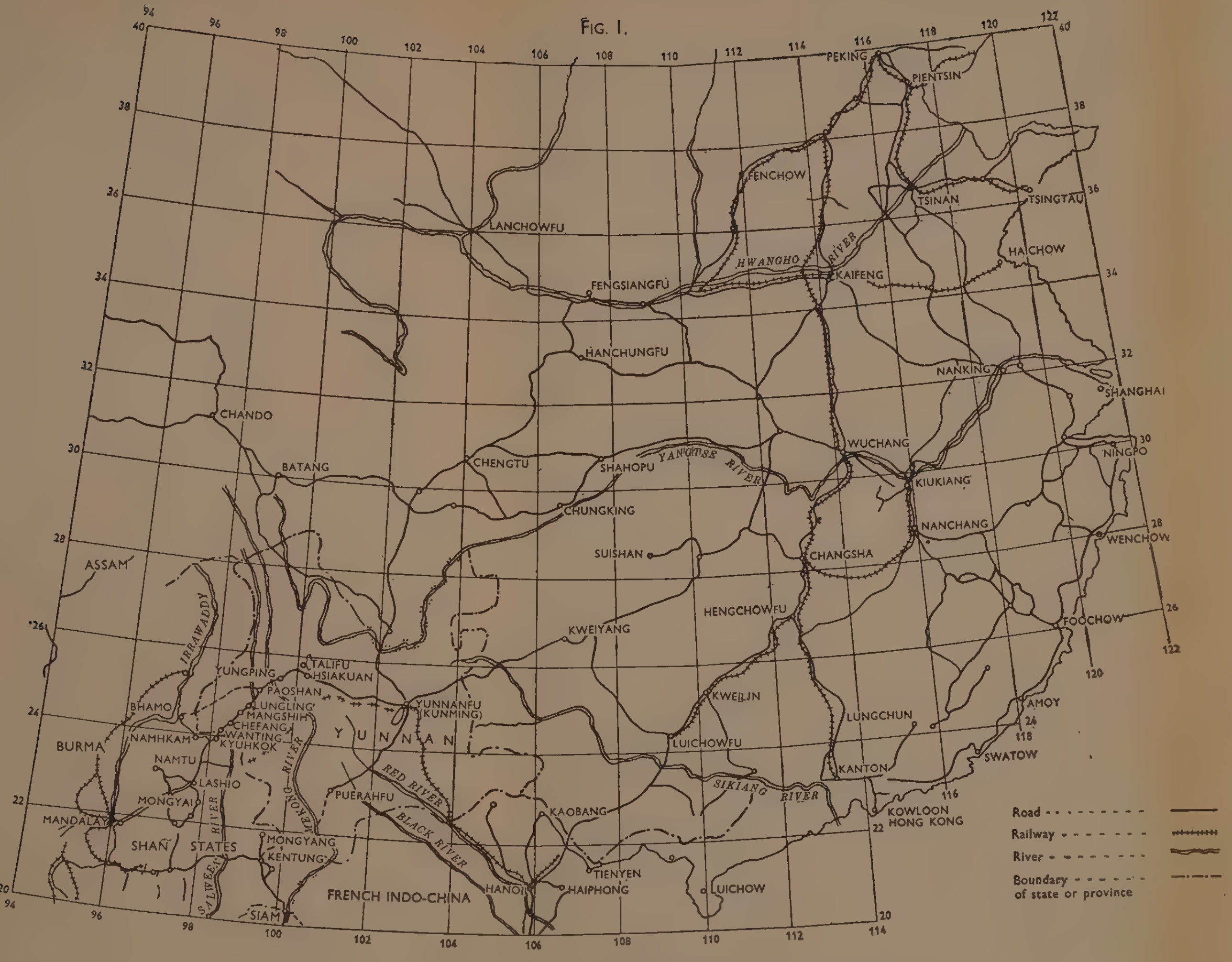
Trackways have been under trial in the Shan States now for about 4 years, but not quite of the Rhodesian specification. Instead of providing the pair of asphalted macadam strips, set into a formation, and surfaced with gravel, the surface of secondary 10-foot metalled roads, after being brought to a condition fit for bitumenizing, has been treated with bitumen in trackways only, and maintained in this way. Each track is 3 feet wide and their centres are spaced 5 feet apart, but at corners the tracks are widened to full width, if necessary. The advantage is mainly in saving on original outlay, as the cost of first-coat painting is about six-tenths that of a 10-foot width. The wear on the edge of the bitumen tracks has not been found to be particularly severe; it is bound to occur with careless driving and bad alinement of the tracks; but after conditions have settled down, and the traffic-lanes have been made sufficiently attractive to cause vehicles to stick to them, the maintenance of the bitumen surface should be little, if any, more than that of the corresponding strips on a 10-foot asphalted road. The centre and sides of the metalling, which have not been bitumenized, also have not given much trouble except on steep gradients, with a little gravel blinding, regularly applied, provided correct camber has been given. The central portion, being laterally nearly horizontal, and contained between the strips, holds its blindage for long periods, but the outer sides require more attention. It seems also that maintenance charges are lower than for a 10-foot width of bitumenizing.

A further improvement on this specification, which has been under trial during the past 2 years is, when finally preparing a metalled road for asphalting, to re-metal only an 8-foot width, and to provide shoulders 1 foot wide on each side, composed of larger stone, hand-packed, and consolidated with the metal. The advantages of this are that the outer edges of the asphalting are supported by the shouldering, and, as the shouldering is rather rough, though not appreciably so, traffic is more inclined to keep to the tracks, so that wear on all four of their edges is reduced. Another advantage is that the stone shoulders are less liable to unravel, or give trouble, than are metalled shoulders, and require less maintenance. The only drawback is that, for fast driving, an 8-foot strip is rather confined, but experience indicates that it is quite adequate. The specification appears to be giving excellent results on secondary roads in open country, but, in hilly country with many corners, it has been found better to bitumenize the full 8-foot width, widening this to 10 feet at corners, or more where curvature is severe. As traffic develops, the first stage of improvement would be the stabilizing of the berms, and the next the provision of a second bitumenized lane.

A type of surface which has not been tried, but which came under review in connexion with the Burma–Yunnan road, is what may be termed a cement-grouted stone road. This appears to be a comparatively new process, the specification for

THE BUR

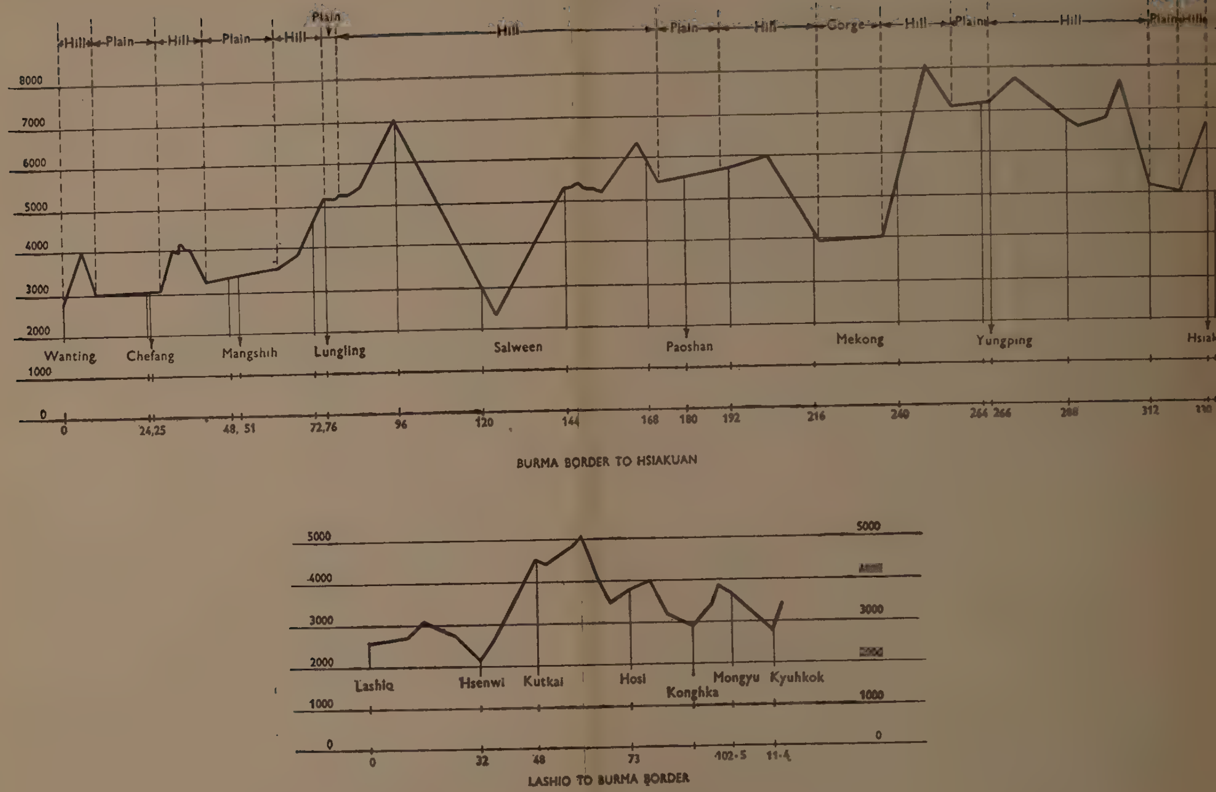
FIG. 1.



Scale: 1 inch = 250 miles approx.

INDEX MAP OF COMMUNICATIONS IN CHINA, SHOWING BURMA-YUNNAN ROAD

FIGS. 2.

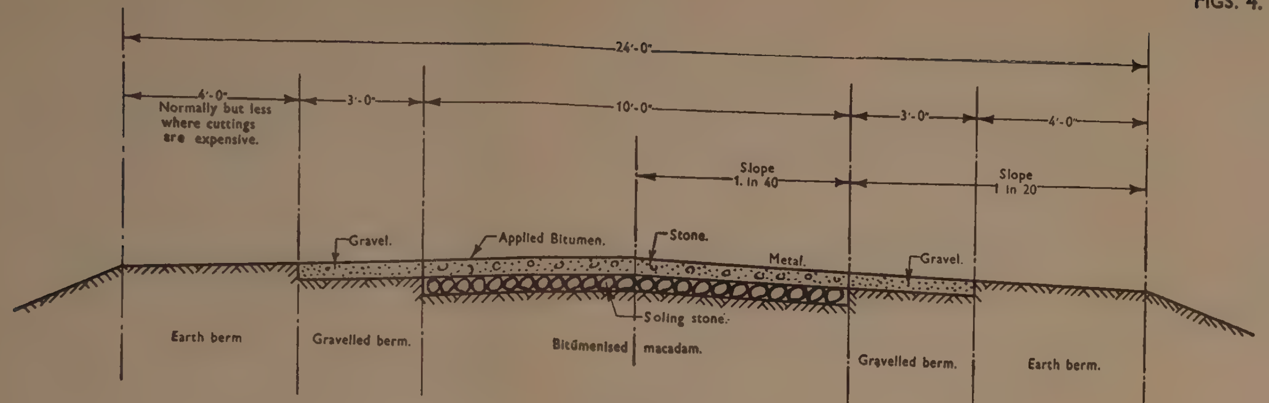


Horizontal scale: 1 inch = 48 miles.
Vertical scale: 1 inch = 4000 feet.

PROFILE OF BURMA-YUNNAN ROAD

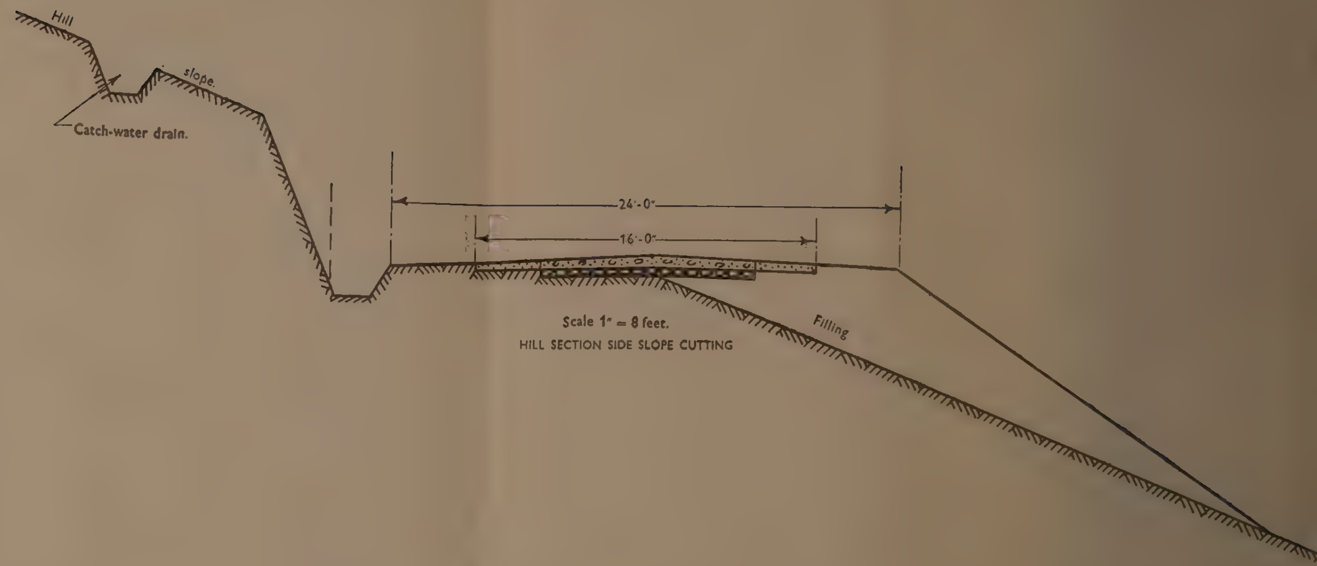
WILLIAM CLOWES & SONS, LIMITED: LONDON.

FIGS. 4.



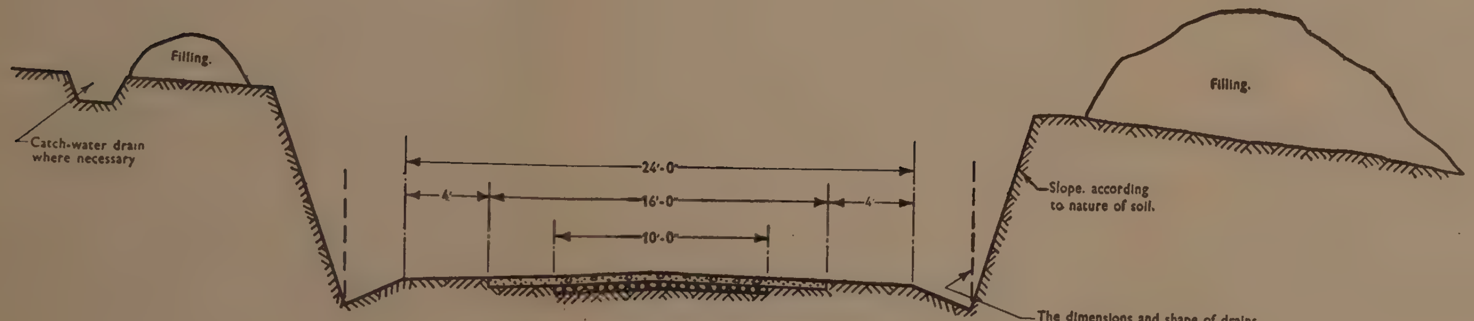
Scale 1" = 4 feet.

CROSS SECTION OF FORMATION



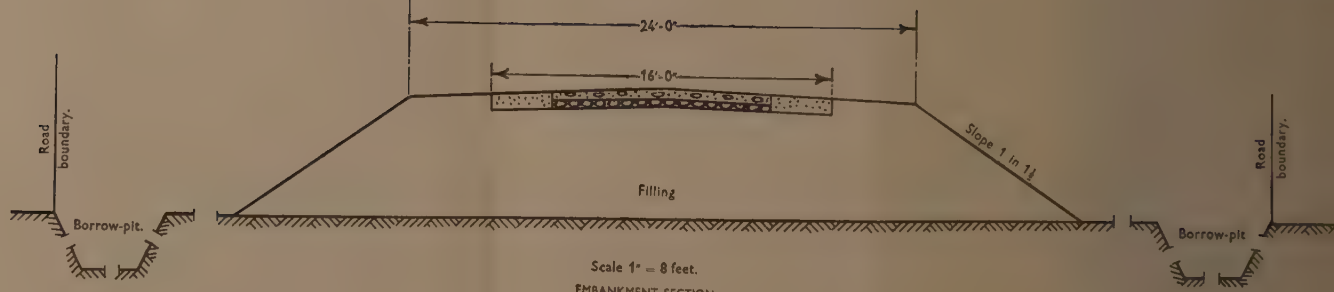
Scale 1" = 8 feet.

HILL SECTION SIDE SLOPE CUTTING



Scale 1" = 8 feet.

HILL SECTION BOX CUTTING



Scale 1" = 8 feet.

EMBANKMENT SECTION

TYPICAL ROAD SECTIONS

which was obtained from England in 1939. It consists of laying a well-packed layer of biggish stones, of a thickness considered suitable to carry the traffic, and filling the interstices with cement grout of whatever mixture is considered desirable. The important point is that the grout is produced by a special machine, which is stated to produce colloidal characteristics, whereby it is less liable to crack under temperature movement, and the cement and sand are less liable to be separated when excessive water is present. The materials are simply fed without measurement into the machine, and the grout is discharged and can be worked and brushed into the interstices. The colloidal characteristics allow sufficient water to be used to enable it to find its way throughout the interstices. As the crust consists of large stones embedded in this stable grout, little or no cracking takes place, and, since mixing with aggregate is avoided, the work can be quickly and easily done, and is considerably cheaper than ordinary cement concrete.

APPENDIX II.

Analysis of Cut-back.

Approximate solvent-content	20 per cent.
Penetration of residue	70–130
Melting-point : °C.	5
Viscosity at 20° F., B.R.T.	110
Flash-point (closed)	140° F.
„ (open)	175° F.
Solubility in CS_2 : per cent.	99·6
Specific gravity at 77° F.	1·02
Pour-point : °C.	6

APPENDIX III.

Traffic Census on the Lashio–Kyuhkok Road.

Period.		Total number of lorries.	Average per day.
9th–31st August	1939	1,524	69
September	„	1,587	53
October	„	2,170	70
November	„	3,182	106
December	„	6,353	205
January	1940	8,140	263
February	„	7,850	271
March	„	6,242	202
April	„	4,812	160
May	„	3,502	113
June	„	4,233	141
July	„	7,191	232
August	„	4,640	150
September	„	6,765	226

INGENUITY COMPETITION, 1941.

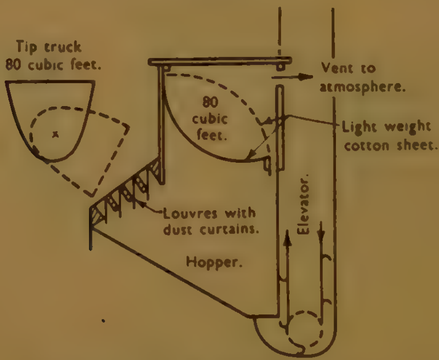
"Overcoming Dust Nuisance from the Discharge of Tip-Wagons into an Elevator Hopper."

By Herbert Cawthra, M.C., Assoc. M. Inst. C.E.

When the Author was asked to deal with the problem, the hopper had already been covered with a hood and fitted with curtained louvres. The tip-trucks discharged through the louvres into the hopper and the curtains prevented much dust rising until the hopper was filled to about half its depth, after which the curtains tended to blow out and exhaust clouds of dust-laden air into the atmosphere.

The first attempts were made with a suction fan and dust cyclone, which collected about 96 per cent. of the dust liberated inside the hood: most of this, however, would have settled naturally in the hopper between

Fig. 1.



the tips without disadvantage: the remainder was of a fine nature and remained suspended in the air for a long time. The period of operation would not warrant the installation of any costly collecting device or heavy running expense, and the additional cost of installing a dust-filter unit could not be justified.

The difficulty was successfully overcome by fitting inside the hood a slack light-weight sheet diaphragm with sufficient fullness to allow an air-displacement equal to the volume of the tip-truck (*Fig. 1*). This acted as a relief bellows, one side being open to the atmosphere so that it could exhaust and refill with clean air. A small dust-escape clearance on the atmosphere exhaust side was left at the lower edge of the bellows sheet, to prevent any accumulation of dust shaken through the sheet material from weighting the bellows sheet and making it too heavy to operate readily.

The Note is accompanied by a diagram, from which the Figure in the text has been prepared.

MADE AND PRINTED IN GREAT BRITAIN BY WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES.

NOTE.—*Pages* [1] *to* [12] *can be omitted when the Journal is bound in volume form.*

NOTICES

No. 3, 1941—42

JANUARY, 1942

GREETINGS TO MEMBERS AND STUDENTS.

Professor Inglis, President of The Institution, desires to convey, on behalf of the Council, cordial greetings and best wishes for the coming year to all Members and Students of The Institution.

MEETINGS, SESSION 1941—42.

ORDINARY MEETING.

The following Papers will be discussed on the dates shown :—

1942.	
Feb. 10 (Tues.) (2 p.m.).	*† "**Soil Mechanics and Site Exploration,**" by L. F. Cooling, M.Sc. with *† "**Soil Mechanics in Road and Aerodrome Construction**", by A. H. D. Markwick, M.Sc., Assoc. M. Inst. C.E.

RAILWAY ENGINEERING SECTION.

1942.	
Jan. 27 (Tues.) (2 p.m.).	†" "**Permanent Way Tests and Practice on the L.M. & S. Railway**", by W. K. Wallace, M. Inst. C.E.

* Brief Synopses of the Papers appeared at pp. [10], [11] of the December Journal.

† Advance proofs, for those who intend to be present, will be available about a fortnight before the meetings, and copies may be obtained upon application to the Secretary.

SPECIAL ANNOUNCEMENTS.

MINISTRY OF LABOUR.

SCHEDULE OF RESERVED OCCUPATIONS.

(REVISION, DECEMBER 1941.)

The following entry appears in the Ministry of Labour's Schedule of Reserved Occupations :—

Student engineering apprentice or learner—age of reservation on 1st December 1941, 18 years.

This entry relates only to a man employed in industry or under articles to a professional engineer who produces a certificate from a university or technical institution or from a professional Institution of Engineers to show that he is within two years of the satisfactory completion of a course of study with a view to offering himself for the first time for :—

(i) an Engineering Degree ;

(ii) an Engineering Higher National Certificate ;

(iii) the Associate Membership Examination of the Institutions of Civil, Mechanical or Electrical Engineers, or the Associate Fellowship of the Royal Aeronautical Society ;

(iv) an engineering examination of similar standing to those in (i), (ii) and (iii) above, e.g. the Associate Membership Examination of the Institution of Marine, Mining and Structural Engineers, Testamur examination of the Institution of Municipal & County Engineers, Higher Grade Certificate in Gas Engineering.

In so far as The Institution of Civil Engineers is concerned, category (iii) applies to Students who are studying with a view to passing Sections A and B of the Associate Membership Examination within a period of 2 years, and who obtain from the Secretary of The Institution certificates to this effect for production to the Registration Officer of the Local Employment Exchange when they register in their age-group under the National Service (Armed Forces) Act, 1939.

A Student who has not yet registered, but who wishes to apply for postponement of calling-up under this entry, must send to the Secretary of The Institution (in good time before the date upon which he is due to register in his age-group under the National Service (Armed Forces) Act, 1939) full particulars of his present occupation, together with documentary evidence in regard to the course of study he is pursuing for Sections A and B of the Associate Membership Examination and an indication of the dates upon which he intends to present himself for those Sections.

The following entry relating to Civil Engineers appears in the Schedule :—

ENGINEER (PROFESSIONAL), CIVIL ENGINEER, AGE OF RESERVATION ON 1ST DECEMBER 1941, 23 YEARS.

The following extracts are taken from the " Explanatory Memorandum' to the Schedule :—

10. " Progressive Raising of Ages of Reservation : Commencing on 1st January 1942, ages of reservation for all occupations in the Schedule, except those specified in Appendix III *, will be raised by one year on the first day of each month. Thus, if the age of reservation for an occupation shown in the Schedule is 25, it will become 26 on 1st January 1942, 27 on 1st February 1942, and so on. Alternative ages of reservation, e.g. 25/35, will become 26/36 on 1st January 1942, 27/37 on 1st February 1942, and so on. A notification will be sent to each man affected by this arrangement stating the date on which he will cease to be reserved and requesting him to inform his employer. Men below the ages of reservation for their occupations, including men who cease to be reserved as a result of the raising of ages of reservation each month, will, where necessary, be retained in industry by means of individual deferment of calling up. Individual deferment will thus gradually replace reservation under the Schedule. The method by which employers should make application for the deferment of the calling up of men who are not reserved is set out in paragraph 11.

11. " Deferment of Calling up of Men Not Reserved : Application may be made for the deferment of the calling up of men, whether engaged on protected or unprotected work, who are not reserved ; such applications will be admitted only where the Minister of Labour and National Service is satisfied that the man for whom deferment is sought is engaged on work of national importance, that the work must continue in order to maintain necessary production or services essential for the community, and that the man cannot be replaced by an older or unfit man, or by a woman. Deferment cannot be granted after an enlistment notice has been issued. Forms of application for deferment (Form N.S. 300) and a leaflet (N.L. 8) explaining the method of making application may be obtained at any local office of the Ministry of Labour and National Service. Application forms, after completion, should be forwarded to the office of the Ministry of Labour and National Service shown on the man's certificate of registration (N.S. 2). Where a man ceases to be reserved under the arrangement for the progressive raising of ages of reservation (paragraph 10) any application by his employer for the deferment of his calling up must be made at least 15 days before the date on which he ceases to be reserved. If the employer does not make such an application, an opportunity will be given

* This Appendix relates to Merchant and Shipping Services, certain Civil Defence Workers, etc.

to the man to make an application for deferment when he is called for medical examination."

MILITARY SERVICE.

POSTING OF STUDENTS OF THE INSTITUTION TO THE ROYAL ENGINEERS.

I. Students of The Institution who do not intend to apply for reservation under the entry in the Schedule of Reserved Occupations relating to a "student engineering apprentice or learner—reserved from the age of 18 years," for the purpose of sitting for Sections A and B of the Associate Membership Examination—should register as "Pupil Civil Engineers", applying beforehand to the Secretary, Inst. C.E., for the appropriate certificate for presentation to the Registration Officer.

Such Students who desire to enter the Corps of Royal Engineers should, as soon as they register, at once forward the following information to the Secretary, Inst. C.E. (who will notify the War Office accordingly), and endeavours will then be made for them to be so posted when called up:—

(1) Occupational Classification No.
(2) Registration No. under the National Service (Armed Forces) Acts, 1939–41.
(3) National Registration Identity No.
(4) Date and place of registration.

If, however, a Student on being called up is ordered to report for service with any other Arm, he should immediately report the fact to the Under-Secretary of State, War Office (A.G.7), Cheltenham, and simultaneously notify the Secretary, Inst. C.E., when the question of his transfer to the Royal Engineers will be taken up at once.

II. Students of The Institution who apply for reservation under the entry in the Schedule of Reserved Occupations referred to on p. [2] of this Number of the Journal should register as "student engineering learners".

As soon as their age-group has been called for registration they should similarly notify the Secretary, Inst. C.E., of the details of their registration, as required under (1), (2), (3), and (4) above.

Such Students who pass Sections A and B and whose reservation under the entry in the Schedule consequently expires, will, in due course, appear before a University Joint Recruiting Board. Immediately upon being notified to attend for interview by such a Board Students concerned should inform the Secretary, Inst. C.E. (who will transmit the information to the War Office), that they are appearing before a Joint Recruiting Board (or that they have notified the Ministry of Labour and National Service in regard to appearing before a Board) in order that their disposal by the Board may be watched, with a view to their being placed in the technical work for which they are most suited. If allotted to the Army,

it is expected that they will in almost all cases be posted to the Royal Engineers.

ARMY OFFICERS' EMERGENCY RESERVE.

It is anticipated that the War Office may require gentlemen of between 31 and 40 years of age for the Works Services (Royal Engineers) at home and abroad, but it is not possible at this stage to give the number or the dates on which they will be needed.

These gentlemen, provided they are in reserved occupations, may be given direct commissions from civil life. After commissioning they will be given a short course in Military Duties and Works Services procedure.

Corporate members who wish to be considered for these Commissions should send their names to the Secretary of The Institution for transmission to the appropriate department of the War Office.

Particulars of a revised method of entry to the Royal Engineers for Associate Members between 25 and 31 years of age may be obtained from the Secretary of The Institution.

POST-WAR NATIONAL DEVELOPMENT.

An Interim Report of the Post-War National Development Committee on matters contained in the Report of the Royal Commission on the Distribution of the Industrial Population (January 1940), and particularly on the form and functions of the proposed central planning authority, was submitted to the Ministry of Works and Buildings in July last. The Report, which deals with the functions and constitution of the proposed national authority, the establishment of regional boards, the desirability of a reduction in the number of local authorities, the dimensions of industrial areas, national defence and the dispersion of industry, classes of industry susceptible to distribution, planning control and development, and other matters, has been printed in pamphlet form. Copies may be had on application to the Secretary.

GENERAL ANNOUNCEMENTS.

THE JOURNAL.

The next Number of the Journal will be published on the 15th February.

SUBSCRIPTIONS.

Members and Students are reminded that subscriptions for 1942 are due on the 1st January, 1942. The present subscription rates are as shown below :—

	Class A. (London Area.)			Class B. (Elsewhere in British Isles.)			Class C. (Abroad.)		
	£	s.	d.	£	s.	d.	£	s.	d.
Members	6	6	0	4	4	0	3	13	6
„ (retired)	3	13	6	2	12	6	2	12	6
Associate Members	3	13	6	2	12	6	2	12	6
„ „ (retired) . .	2	12	6	2	2	0	2	2	0
Associates	5	0	0	5	0	0	5	0	0
Students	2	0	0	1	10	0	1	10	0

Owing to the increased cost of postage and need for economy in the use of paper, members are urged to make prompt payment of their subscriptions and so save the necessity of a further application.

Attention is drawn to the fact that any contribution to the Benevolent Fund may be included in the cheque drawn in payment of the Institution subscription.

ALFRED YARROW EDUCATIONAL FUND.

The Committee of Management of the Alfred Yarrow Educational Fund wish to say that applications for assistance from the Fund for consideration in 1942 should be lodged before the 1st June, 1942. The income of the Fund, which is derived from a donation of £10,000 by the late Sir Alfred Yarrow for educational purposes, is applied for the purpose of educating the sons and daughters of members of The Institution of limited means, or the sons and daughters of deceased members, as day scholars or boarders at schools of good standing. Children must be upwards of 13 years of age. Full particulars may be obtained on application to the Hon. Secretary of the Alfred Yarrow Educational Fund, c/o The Institution of Civil Engineers.

ELECTION, ADMISSION, AND EXAMINATIONS.

Copies of the Forms required in connexion with proposals for Election to Corporate Membership, recommendations for Admission to Studentship, and by Students for entry for the Associate Membership Examination, may be obtained on application to the Secretary, who will be pleased at all times to deal with inquiries on these matters.

Students who wish to enter for the April, 1942, Associate Membership Examination at home, which is to be held from the 20th to the 24th, inclusive, of that month, are reminded that their completed applications to attend should be in the Secretary's hands by the 28th February.

PORTRAIT.

The Council have had pleasure in accepting on behalf of The Institution a portrait in oils of Sir Clement D. M. Hindley, K.C.I.E., Past-President, painted by Anthony Devas.

TRANSFERS AND ADMISSIONS.

Since the 18th November 1941, the Council have transferred eight Associate Members to the class of Members, and have admitted eighty-nine Students.

DEATHS AND RESIGNATIONS.

The Council have received, with regret, intimation of the following deaths and resignations :—

Deaths.

Ball, John, O.B.E., Ph.D., D.Sc. (E. 1899. T. 1911.)	*Member.*
Jones, Henry. (E. 1910.)	,,
Knight, John Douglas. (E. 1908. T. 1920.)	,,
Mair, Robert, M.C., B.Sc. (E. 1917. T. 1933.)	,,
Robinson, Henry. (E. 1913. T. 1922.)	,,
Wilson, Albert, B.Sc. (E. 1904. T. 1928.)	,,
Early, Sydney Charles. (E. 1887.)	*Associate Member.*
Lawrence, Ronald Mackenzie. (E. 1920.)	,, ,,
Owens, John Switzer, M.D. (E. 1902.)	,, ,,
*Vowles, Peter Timothy. (A. 1935.)	*Student.*

* *Killed on Active Service.*

Resignations.

Collett, Charles Benjamin, O.B.E. (E. 1922.)	*Member.*
Dickson, Norman Bonnington. (E. 1895. T. 1901.)	,,
Longbottom, William. (E. 1912. T. 1924.)	,,
Thurston, James Henry. (E. 1919.)	,,
Bowness, James Lord. (E. 1906.)	*Associate Member.*
Brierley, James, O.B.E. (E. 1908.)	,, ,,
Carr, Lawrence Statter. (E. 1894.)	,, ,,
Clark, Albert Hawkins. (E. 1905.)	,, ,,
Coad, Harold Eustace. (E. 1907.) (*Col. Staff for R.E. Services.*)	,, ,,
Glendinning, John Hastings, B.Sc. (E. 1926.)	,, ,,
Hague, Harold Wilfrid. (E. 1916.)	,, ,,
Ker, Andrew Martin, B.Sc. (E. 1902.)	,, ,,
Palmer, William Lowell Francis. (E. 1906.)	,, ,,
Rogers, James Shaw. (E. 1904.)	,, ,,
Hedger, Ian Rendell. (A. 1939.)	*Student.*

A SELECTIVE LIST OF RECENT ADDITIONS TO THE LIBRARY.

[Journals, Proceedings of Societies, etc., are not included.]

Accountancy. Bangs, R., and Hanselman, S. R. "Accounting for Engineers." 1941. International Textbook Co. 24*s.*

Aircraft. *See* Diesel Engines.

Aluminium. Jenny, A. "Anodic Oxidation of Aluminium and its Alloys." 1940. Griffin. 16*s.*

*Bakelite. Cockcroft, N. W. W. "Mechanical Properties of Laminated Bakelite." 1941. Chelmsford. (Typed paper.)

*Biography. Royal Institute of British Architects. "Sir Christopher Wren, 1632–1723. Bicentenary Memorial Volume." 1923. Hodder & Stoughton. £8 8*s.* 0*d.*

Colloids. Hauser, E. A. "Colloidal Phenomena." 1939. McGraw-Hill. 18*s.*

Diesel Engines. Wilkinson, P. H. "Aircraft Diesels." 1940. Pitman. 30*s.*

EARTHQUAKE-RESISTANT CONSTRUCTION. *See* STRUCTURES.

ELECTRICITY—LAMPS. FRANCIS, V. J., and JENKINS, H. G. "Electric Discharge Lamps." 1941. General Electric Co. No price.

FISHWAYS. NEMENYI, P. "An Annotated Bibliography of Fishways." 1941. Iowa State Univ., Ames. Bulletin 33. 3*s*.

HOUSING. FIELD, W. B. "House Planning." 1940. McGraw-Hill. 21*s*.

*LAND DRAINAGE. WITHAM AND STEEPING RIVERS CATCHMENT BOARD. "Report on Various Schemes for Improvement of Main Drainage of the Black Sluice Internal Drainage District," by F. H. Tomes. 1938. Boston. No price.

MECHANICAL ENGINEERING. LOW, D. A. "A Pocket Book for Mechanical Engineers." 1938. Longmans Green. 12*s*. 6*d*.

MECHANICS. JEANS, J. H. "Elementary Treatise on Theoretical Mechanics." 1935. Ginn. 21*s*.

METALS. *See* STRENGTH OF MATERIALS AND STRUCTURES.

PILES AND PILING. APPLEBY-FRODINGHAM STEEL CO., LTD. "Steel Sheet Piling." 1941. The Company, Scunthorpe, Lincs. Gratis. Apply direct on business notepaper giving position.

PROFESSIONAL CONDUCT. AM. SOC. C.E. "Standards of Professional Relations and Conduct." (Manual of Engineering Practice 21.) 1940. The Society, New York. 50 cents.

RIVETS. PEARSE, W. W. "Eccentric Application of Loads to Groups of Rivets." 1940. Ryerson Press, Toronto. 15*s*.

ROOFS. PARKER, H. "Simplified Design of Roof Trusses for Architects and Builders." 1941. Chapman & Hall. 15*s*.

SANITARY ENGINEERING. MITCHELL, G. E. "Modern Sanitary Engineering." 1941. Newnes. 12*s*. 6*d*.

SCIENCE. GREGORY, *Sir* R. "British Scientists." 1941. Collins. 3*s*. 6*d*.

—— KAPP, R. O. "Science versus Materialism." 1940. Methuen. 10*s*. 6*d*.

SEWAGE DISPOSAL AND SEWERAGE. RUDOLFS, *Dr*. W. "Principles of Sewage Treatment." 1941. National Lime Assoc., Washington. 3*s*.

SOIL. HALL, *Sir* A. D. "The Soil." 4th ed. 1931. Murray. 9*s*.

SOIL MECHANICS AM. SOC. C.E. "Selected Bibliography on Soil Mechanics." 1940.

—— —— "Soil Mechanics Nomenclature." 1941. (Manuals of Engineering Practice 18 and 22.) The Society, New York. 1 dollar and 40 cents. respectively.

STRENGTH OF MATERIALS AND STRUCTURES. CLARK, D. A. R. "Materials and Structures." 1941. Blackie. 25*s*.

—— BATTELLE MEMORIAL INSTITUTE. "Prevention of the Failure of Metals under Repeated Stress." 1941. Chapman & Hall. 16*s*. 6*d*.

STRUCTURES. CROOKES, S. I., *Jr*. "Structural Design of Earthquake-Resistant Buildings." 1940. Leighton, Auckland, N.Z. 25*s*.

TELEVISION. LOHR, L. R. "Television Broadcasting." 1940. McGraw-Hill. 21*s*.

WATER. AM. SOC. C.E. "Water Treatment Plant Design." (Manual of Engineering Practice 19.) 1940. The Society, New York. 1 dollar 90 cents.

WIRELESS. WATSON, H. M., and others. "Understanding Radio." 1940. McGraw-Hill. 20*s*.

(* *The foregoing books, with the exception of those marked with an asterisk, may be borrowed from the Loan Library.*)

LOCAL ASSOCIATIONS.

The following arrangements have been made for forthcoming meetings of the Local Associations. The arrangements are in the hands of the Committees of the Associations concerned and all communications respecting them should be addressed to the respective Honorary Secretaries :—

EDINBURGH AND DISTRICT ASSOCIATION.

Feb. 11. "Some Foundation Problems and Soil Action", by A. R. Pollard, B.A., M. Inst. C.E.

Mar 11. Film illustrating the Failure of the Tacoma Narrows Suspension Bridge.

GLASGOW AND DISTRICT ASSOCIATION.

Jan. 30. Film illustrating the Failure of the Tacoma Narrows Suspension Bridge (at the Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow (6 p.m.).

NORTHERN IRELAND ASSOCIATION.

Feb. 23. "Town Re-planning", by Captain Brown.

Mar. 30. Meeting to be arranged.

Apr. 27. Annual General Meeting.

NORTH-WESTERN ASSOCIATION.

Feb 14. "The Aesthetics of Engineering Structures", by D. T. Lloyd Jones.

Mar. 21. "Soil Mechanics and Site Exploration", by L. F. Cooling, M.Sc.

Apr. 25. "The Engineer's Part in Town Planning", by H. J. Manzoni, C.B.E., M. Inst. C.E.

SOUTH WALES AND MONMOUTHSHIRE ASSOCIATION.

Feb. 21. Meeting to be arranged (at Swansea).

Apr. 18. Annual General Meeting (at Cardiff).

YORKSHIRE ASSOCIATION.

Feb. 28. Film illustrating the Failure of the Tacoma Narrows Suspension Bridge (at Sheffield).

Mar. 7. Joint meeting with the Yorkshire Association of the Institution of Mechanical Engineers. The Thomas Hawksley Lecture by Mr. W. T. Halcrow (at Sheffield).

REPORTS.

Birmingham and District Association.

On Saturday, 22 November, at a joint meeting with the local branches of the Institutions of Structural and Municipal and County Engineers, the film illustrating the Failure of the Tacoma Narrows Suspension Bridge was exhibited.

Bristol and District Association.

The film illustrating the Failure of the Tacoma Narrows Suspension Bridge was exhibited at a meeting held on Thursday, 4 December.

Edinburgh and District Association, North-Western Association, and the South Wales and Monmouthshire Association.

Members of the foregoing Associations attended, by invitation, meetings of branches of the Institution of Mechanical Engineers on the 5th and 13th December, and the 28th November, respectively, when the Thomas Hawksley Lecture on " A Century of Tunnelling ", by Mr. W. T. Halcrow, was repeated.

Southern Association.

At a meeting at Southampton on Saturday, 22 November, Mr. M. C. Privett, B.Sc., Stud. Inst. C.E., read a Paper on " Modern Methods of Piling."

Yorkshire Association.

The following meetings have been held : Saturday, 22 November, joint meeting with the Yorkshire Branch of the Institution of Structural Engineers at Leeds, when a number of short papers on " Wartime Expedients " were presented by members of the two Associations; Saturday, 6 December, at Sheffield, when Mr. H. J. Paul, M. Inst. C.E., read a Paper on " Mining Subsidence and some Drainage Problems arising therefrom."

SYNOPSIS OF INAUGURAL ADDRESS

of Mr. R. D. Duncan, B.Sc., M. Inst. C.E.,

Chairman of the Northern Ireland Association.

Meeting, 27 October 1941.

After thanking the Association for his election as Chairman, Mr. Duncan apologized for departing from precedent by not choosing a technical subject, but said that he had been interested for some time in securing a more complete unity between the Association and the students of Queen's University. He felt satisfied that if these students realized the advantages to be obtained by closer contact with practising engineers, such contact would be assured. The Association was gratified that these views were shared by the parent body, and it was hoped that certain arrangements could be made to secure the desired result.

In the present circumstances, and those visualized after the war, it was necessary to keep up the supply of engineers and to ensure that their

training was such as would fit them to tackle the vital problems now existing, and also those bound to arise later.

There was much controversy over the training of engineers, but Mr. Duncan suggested that pure mathematics should not be over-emphasized, and that mathematics, which were only a means to an end, should be taught in association with the technical applications. This would result in both subjects being assimilated with less effort. He hoped that certain chemistry and mineralogy studies, although most interesting in themselves, might give place to the chemistry of cements and paints, and to soil-mechanics.

His own experience as a pupil, and his contact with graduates generally, suggested that young men required more assistance at that stage to make sure that they entered suitable employment. It was essential that all engineers had a balanced training. Designing staff required outside experience, and vice versa. Specialization should not be premature.

Engineers often lacked ambition but were very enthusiastic on their immediate problem. Many managerial posts should be occupied by engineers instead of by legal or financial men, and instances were quoted. Engineers, however, to be worthy of such posts must broaden their experience and must continue to study after leaving college. Study on the technical side was needed and could sometimes be carried out on jobs if the subject were germane to the work in hand. In this way the young engineer would derive great benefit.

He thought British engineers were still too conservative, particularly in the matter of facilities for visits to foreign countries and for attendance at refresher courses. A better bibliography on the lines of the Institution's "Engineering Abstracts" seemed necessary.

It was suggested that Government, local authorities, consultants, and contractors should contribute to assist the University to augment its testing facilities.

The use of poor aggregates was held up as an example of a technique requiring urgent improvement, and the institution of a trade of concreters was mentioned as a step in the direction of improved quality in concrete construction.

Post-war reconstruction and development was liable to suffer irreparably if legislation was not simplified and crystallized in advance.

Few professions, Mr. Duncan suggested, afforded such complete satisfaction to their members. There was a possessive feeling on regarding a completed work, which was natural as the creative spirit embodied personal interest and effort. Engineering works were more artistic than some people imagined ; they had an inherent beauty derived perhaps from the suggestion of immense power harnessed to the service of man.